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JOURNAL
WATERWAYS AND HARBORS DIVISION
Proceedings of the American Society of Civil Engineers

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JOURNAL
WATERWAYS AND HARBORS DIVISION
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WAVE RUN-UP ON SHORE STRUCTURES

Thorndike Saville, Jr., J. M. ASCE[1]
(Proc. Paper 925)

SYNOPSIS

Laboratory tests determining run-up on shore structures as a result of wave action are described. Curves relating the run-up to wave steepness, structure type, and depth at structure toe are presented.

INTRODUCTION

A need for more adequate design data on the height of wave run-up on shore structures has long been evident, with many protective structures along the shores of rivers, lakes, reservoirs, and the oceans having been designed to meet run-up requirements (i.e., freeboard) by essentially rule of thumb methods rather than on a sound factual basis. The vertical height to which water from a breaking wave will run up on a given structure determines the height to which the structure must be raised to prevent overtopping and resultant flooding on the landward side, and, if the structure is a dam or levee, possible destruction by rearface erosion. These crest elevations have usually been determined by applying a rather arbitrarily selected ratio of run-up to wave height (R/H). A value of R/H equal to 1.5 appears to be that most frequently used, although values as low as 0.9 and as high as 2 have been suggested for particular designs. It has been generally recognized that the correct value would depend on the structure characteristics (i.e., shape and roughness), the water depth at its toe, and the wave characteristics, but sufficient data has not been available to accurately determine these relationships. The value of 1.5 is the one which is given for general use by the Beach Erosion Board[(1)] for structures in, or landward of, the breaker zone. The (Dutch) Technical Laboratory at Delft has determined an approximate value, from a relatively small number of observations, of R/H equal 8 tan θ, where θ is the structure slope;[(2)] if a berm of width B is placed at the mean water level, the

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ratio can be reduced by a factor of (1-B/L), where L is the wave length. This ratio is for "an open regularly set stone revetment and width of berm of about 1/4 of the wave length L." It is further stated that a smooth impervious facing increases the run-up by about 15%, while a rough stepped facing can decrease it about 10%. Some model study data obtained at the University of California has also been published by Granthem[3] for smooth slopes of 15, 30, and 45 degrees. In addition to the need for data for the more conventional types of shore structures, the increasingly frequent use of artificially placed fill as a protective (beach) structure has led to a need for data on relatively gentle slopes (i.e., 1 on 10 to 1 on 30) to enable an adequate design of beach berm elevations.

Recognizing the lack of basic data, the Beach Erosion Board, as a part of its general research program on factors basic to shore protection and the design of shore structures, initiated in 1952 a comprehensive test program of a generalized nature on wave run-up and its accompanying factor wave overtopping. Some of these tests (including all of those on wave overtopping) have been carried out at the Waterways Experiment Station of the Corps of Engineers at Vicksburg, Mississippi, in accordance with a test schedule prepared by the Board; others have been carried out in the Board's laboratory. A preliminary analysis of the overtopping data on the vertical wall has been presented by Saville and Caldwell,[4] and a tabular summary of the Vicksburg data (without analysis) has also been published.[5] The present report presents an analysis of the run-up data taken at both laboratories.

Test Facilities and Procedure

The test program at the Waterways Experiment Station was carried out in a concrete flume 120 feet long, 5 feet wide, and 5 feet deep. Waves were generated by a plunger type wave machine in which the wave period could be regulated by varying the speed of the motor, and the wave height by varying the eccentricity of the plunger arm and hence the depth of penetration of the plunger. The tests at the Beach Erosion Board were carried out in a steel wave flume 96 feet long, 1.5 feet wide, and 2 feet deep. The pusher-type wave generator consisted of a vertical bulkhead attached eccentrically through a pusher arm to a rotating (driving) disk 2 feet in diameter. The disk was driven by a 2 1/2 HP motor through a vari-drive unit. The wave period could be adjusted by varying the gear ratio in the vari-drive unit, and the wave height by varying the eccentricity of the connecting rod and hence the travel distance of the bulkhead. In both cases waves of known characteristics were propagated against the test structure at the opposite end of the tank (Figure 1). The Vicksburg test structures were tested in one, two, or three different depths of water at the structure toe, these depths being obtained by varying the depth in the deep portion of the tank. The structures tested were a vertical wall, a curved wall (based on the Galveston seawall section), a similar curved wall but with recurvature at the top, smooth slopes of 1 on 3 and 1 on 1 1/2, a step-faced wall of 1 on 1 1/2 slope, and a riprap faced wall of 1 on 1 1/2 slope (one layer of riprap on an impermeable base). All structures were fronted by a 1 on 10 beach slope. All the Board test structures were tested with four depths at the structure toe, these depths being obtained by keeping the water level in the deep portion of the tank constant (at 1.25 feet) and varying the location of the structure (Figure 1). The structures tested were smooth slopes of 1 on 1 1/2, 1 on 2 1/4, 1 on 3, 1 on 4, and 1 on 6. As with the Vicksburg

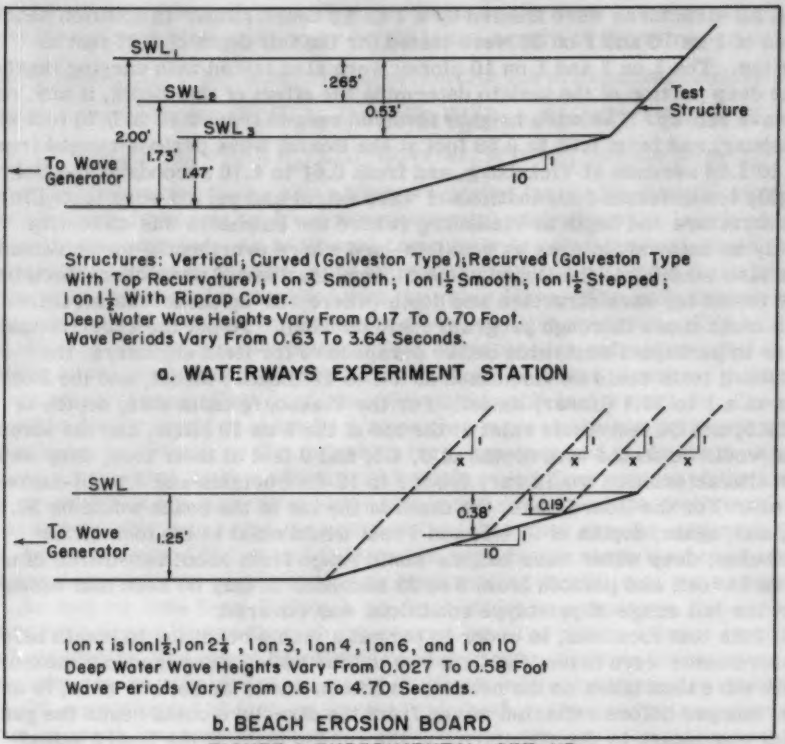

SWL1
SWL2
SWL3
.265'
0.53'
2.00'
1.73'
1.47'
To Wave Generator
Test Structure
1
10
Structures: Vertical; Curved (Galveston Type); Recurved (Galveston Type With Top Recurvature); 1 on 3 Smooth; 1 on 1½ Smooth; 1 on 1½ Stepped; 1 on 1½ With Riprap Cover.
Deep Water Wave Heights Vary From 0.17 To 0.70 Foot.
Wave Periods Vary From 0.63 To 3.64 Seconds.
a. WATERWAYS EXPERIMENT STATION
SWL
To Wave Generator
1.25'
0.38'
0.19'
1 on x is 1 on 1½, 1 on 2¼, 1 on 3, 1 on 4, 1 on 6, and 1 on 10
Deep Water Wave Heights Vary From 0.027 To 0.58 Foot
Wave Periods Vary From 0.61 To 4.70 Seconds.
b. BEACH EROSION BOARD

FIGURE 1. EXPERIMENTAL SET-UP

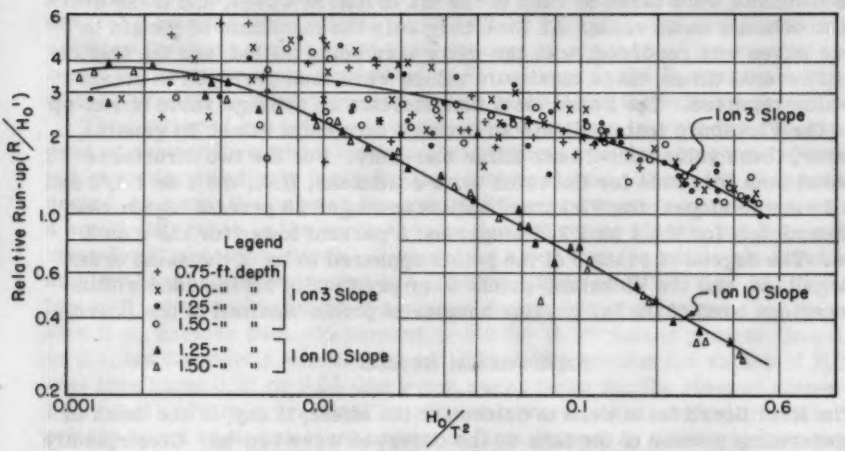


FIGURE 2. EFFECT OF TANK DEPTH

tests, all structures were fronted by a 1 on 10 beach slope. In addition beach slopes of 1 on 10 and 1 on 30 were tested for the full depth of 1.25 feet at their toe. The 1 on 3 and 1 on 10 slopes were also tested with varying depths in the deep portion of the tank to determine the effect of this depth, if any, on the wave run-up. The wave heights involved ranged from 0.17 to 0.70 foot at Vicksburg, and from 0.03 to 0.58 foot at the Board; wave periods ranged from 0.63 to 3.64 seconds at Vicksburg, and from 0.61 to 4.70 seconds at the Board. Roughly ten different combinations of wave height and period were tested for each structure and depth at Vicksburg (where the emphasis was on testing quickly as many structures as possible—and where overtopping measurements were also made). At the Board some 51 combinations of wave characteristics were tested for each structure and depth (where run-up alone was measured, and a much more thorough program could be used). To put the experimental values in perhaps a somewhat better perspective for field engineers, the Vicksburg tests could be visualized as a 1 to 17 (linear) model, and the Board tests as a 1 to 23.7 (linear) model. For the Vicksburg tests then, depths of 25, 29.5, and 34 feet would exist at the toe of the 1 on 10 slope, and the structures would be tested with depths of 0, 4.5, and 9 feet at their toes; deep water wave characteristics would vary from 3 to 12-foot heights and 3 to 15-second periods. For the Board tests, the depth at the toe of the beach would be 29.5 feet, and, again, depths of 0, 4.5, and 9 feet would exist at the toes of the structures; deep water wave heights would range from about two-thirds of a foot to 14 feet, and periods from 3 to 23 seconds. It may be seen that essentially the full range of prototype conditions was covered.

At both test locations, in order to permit a stable condition to obtain before measurements were taken, the first two to four waves were ignored; measurements were then taken on the next six to fifteen waves or so, but were, in any case, stopped before reflected waves from the structure could reach the generator and return to the structure. In the run-up tests at the Board actual measurements were taken on each of the six to fifteen waves, and these averaged to obtain a mean value. At Vicksburg only the maximum of the six to fifteen waves was recorded, with the water then being stilled, and the test repeated several times; these maximum values were then averaged to obtain the value reported. The Board tests thus indicate an average value of run-up while the Vicksburg tests indicate an average maximum value. In general, however, these values should not differ markedly. For the two structures tested at both locations for the same wave conditions, (i.e., the 1 on 1 1/2 and 1 on 3 smooth slopes) the Vicksburg values averaged 28 percent higher than the Board data for the 1 on 1 1/2 slope, and 6 percent lower for the 1 on 3 slope. The degree of scatter of the points appeared to be of the same order of magnitude, and the Vicksburg points were practically all included within the envelope band of the far greater number of points obtained at the Board.

Experimental Results

The first Board tests were to determine the effect, if any, of the depth in the generating portion of the tank on the observed wave run-up. Consequently tests were initially run for the 1 on 10 slope with two, and for the 1 on 3 slope with four, different depths in the deep portion of the tank. For each of these cases the slope extended uniformly through the entire depth to the bottom of the tank. The points obtained are plotted in Figure 2.

The values plotted are relative run-up (the ratio of vertical rise of water

on the structure face above still water level, to the deep water wave height) and the ratio of deep water wave height to the square of the wave period. The latter value (H'_o/T^2) is directly proportional to the dimensionless value of deep water steepness (H'_o/L_o). (Actually $H'_o/L_o = H'_o/(gT^2/2\pi)$, and so $H'_o/T^2 = gH'_o/2\pi L_o = 5.12\ H'_o/L_o$.) However, it is felt that the term H'_o/T^2 is somewhat easier to use since the wave period is usually directly available (either from forecasts or from measurements) while the wave length generally must be computed. An additional complexity in using the wave length as a parameter is that it changes quite appreciably with depth, and a depth position must therefore be specified with the value given. The wave period, on the other hand, remains constant regardless of depth variation. The height parameter used is the deep water height corrected for refraction—that is the height which would exist in deep water offshore from the structure if there were no refraction effect (i.e., the refraction coefficient were 1.0). The breaker height would perhaps be a somewhat more desirable parameter, but is extremely difficult to obtain both in the laboratory and in the field. Any other height (such as that which would obtain in the deep portion of the tank or at the toe of the structure) again requires definition of the depth involved, and complicates somewhat the usage of the laboratory results—although this is not as important for wave height as for wave length since the height change is usually relatively small as long as the breaking condition is not approached.

As may be seen from Figure 2, no depth effect was apparent, and curves have been drawn by eye through the general mass of points. From a practical standpoint, this might be related to design of an offshore breakwater, and whether run-up considerations would differ were it to be located in depths of 50, 70, or perhaps 100 feet; or whether the depth at the base of a reservoir dam or river levee would make any difference in freeboard requirements. Actually the independence of run-up on depth for relatively large depths (say several times the wave height) might well be expected—but considerable question has been raised about it at one time or another. This result is also borne out by other tests performed at Vicksburg for the Jacksonville District of the Corps of Engineers for the design of the Lake Okeechobee levees.(6)

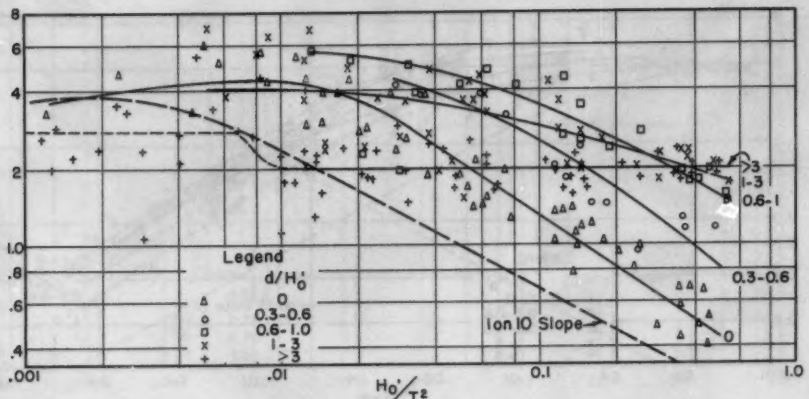
The scatter of the points about the derived curves is quite typical, the degree of scatter throughout the tests being very small for the gentle slopes, but becoming relatively large for the steeper slopes. This also is to be expected, as a relatively large horizontal difference in wave uprush means only a small difference in the vertical value for the gentle slopes, but becomes large for the steeper slopes. It should be noted that the scatter is much smaller for the steeper waves (i.e., larger values of H/T^2) than for those of low H/T^2 values. In almost every case the scatter of points was not excessive (i.e., greater than $\pm$20 percent or so) for H/T^2 values greater than 0.08 or 0.1, but frequently was as high as $\pm$100 to 200 percent for values of H/T^2 less than about 0.01 or 0.02 (the worst cases being for the steeper slopes—as 1 on 1 1/2). From a practical standpoint however, this particular scatter pattern is not as bad as it may seem at first glance, as almost always the designer is interested in the higher and steeper waves—and the less steep waves are of very nearly only academic interest. Table 1 shows equivalent values of H/T^2 and wave steepness (H/L) and the wave heights corresponding to these values for various wave periods. As may be readily seen, engineer designers dealing with small bodies of water (lakes, rivers, and reservoirs)

TABLE 1

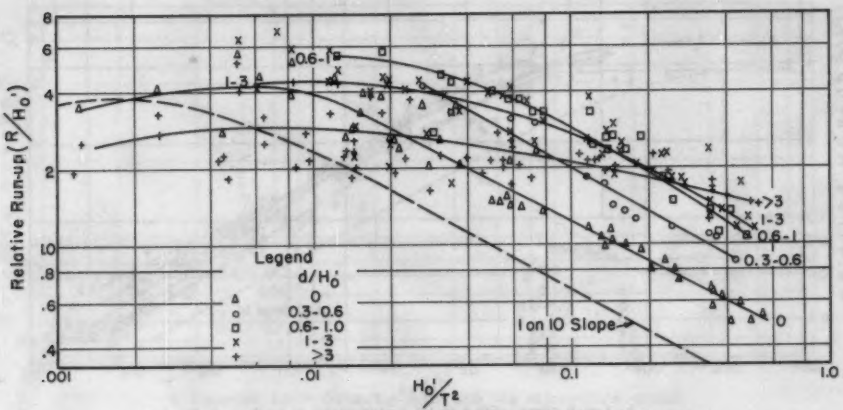
$\frac{H'_o}{T^2}$	$\frac{H'_o}{L_o}$	Wave height corresponding to period of			
		5 sec.	10 sec.	15 sec.	20 sec.
0.5	.0975	12.5	50		
0.2	.039	5	20	45	
0.1	.0195	2.5	10	22.5	40
0.05	.00975	1.25	5	11.25	20
0.02	.0039	0.5	2	4.5	8
0.01	.00195		1	2.25	4

and with the East Coast of the United States where wave periods for storm waves are relatively short, almost always will be dealing with waves of H/T^2 values greater than 0.1, and probably never with values less than 0.05. Designers on the West Coast, where incident wave periods are frequently larger will be dealing relatively frequently with waves of H/T^2 between 0.05 and 0.1, but very seldom with values of less than 0.05 and practically never with values less than 0.02. Consequently the designer will be working in the area where the curves have the least scatter, and appear to be the most accurate—which is indeed a fortunate occurrence.

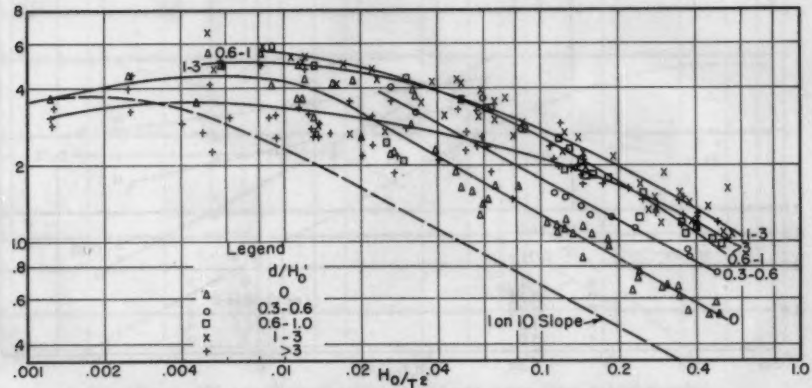
Figure 3 (a-j) shows the points for the various structures tested with the plotted points identified as falling within various ranges of depth-height ratio values, where the depth (d) indicates the depth at the toe of the structure. A very definite relationship is apparent throughout, with the run-up increasing with depth of structure until a depth-height ratio of between about 1 and 3 is reached, and then apparently decreasing somewhat. Actually the apparent decrease as the larger depths are reached appears generally quite small (particularly in the range of greatest interest of values of H/T^2 greater than about 0.05) and may in fact be due only to the difference in scatter of the various points. The initial increase in run-up with depth may be explained by the location of the breaking wave. When the wave breaks offshore from the structure (i.e., shallow structure depths) it acts over a relatively large distance of gentle beach slope before reaching the actual structure. It may be thought of then as essentially acting over a gentler (total combined) slope than when it breaks more nearly on the structure itself—and consequently has a somewhat lower run-up. In each case the curve derived for the 1 on 10 slope (Figure 2) is also shown to aid in comparison. This curve shows the run-up relation which would exist for the (1 on 10) beach slope were the test structure not in place. Were the structure depth to be decreased still further (i.e., the structure toe put at a plus elevation), the resulting run-up curves would approach still more nearly the curve for the 1 on 10 slope. The depth-height ratio ranges chosen were purely arbitrary. The particular ranges used were selected as most conveniently fitting the groups of data taken. The Vicksburg data were taken for five values of this ratio only, and these are shown as specific values rather than as ranges. The symbols used, however,



a. 1 on $1\frac{1}{2}$ slope, with 1 on 10 beach slope from toe of structure

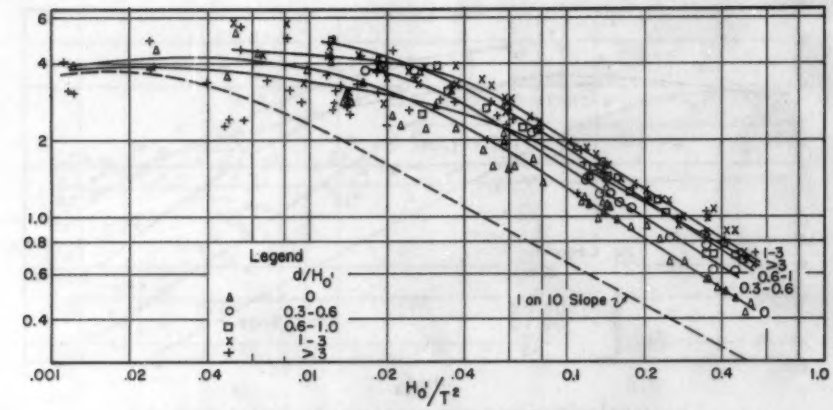


b. 1 on $2\frac{1}{4}$ slope, with 1 on 10 beach slope from toe of structure

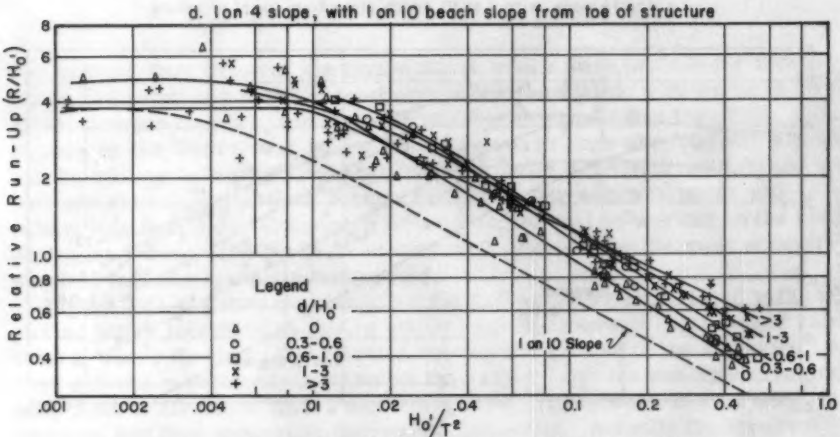


c. 1 on 3 slope, with 1 on 10 beach slope from toe of structure

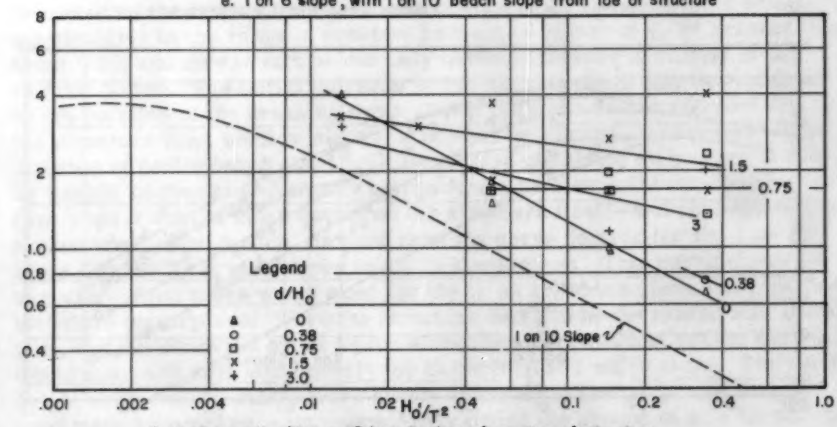
FIG. 3 · RUN-UP AS A FUNCTION OF STRUCTURE DEPTH AND WAVE STEEPNESS



d. 1 on 4 slope, with 1 on 10 beach slope from toe of structure

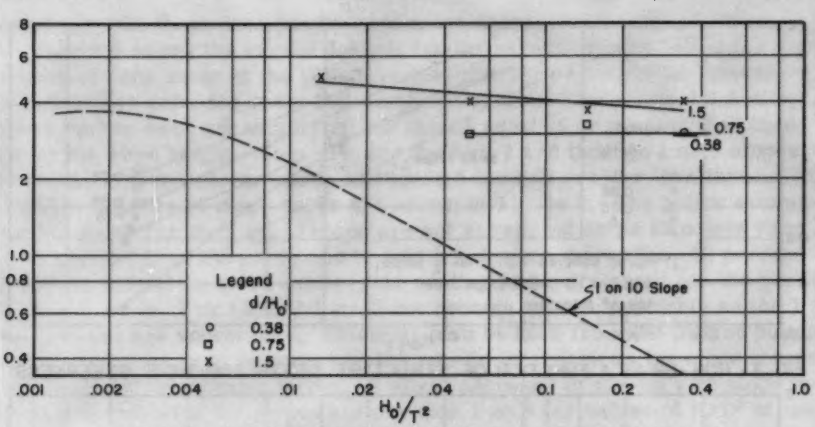


e. 1 on 6 slope, with 1 on 10 beach slope from toe of structure

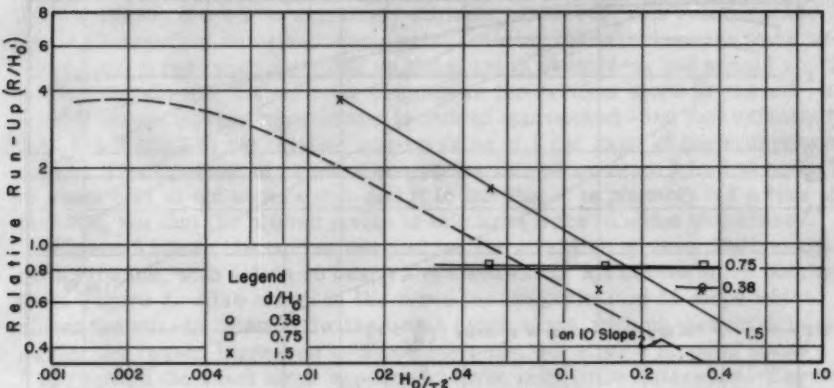


f. Vertical wall with 1 on 10 beach slope from toe of structure

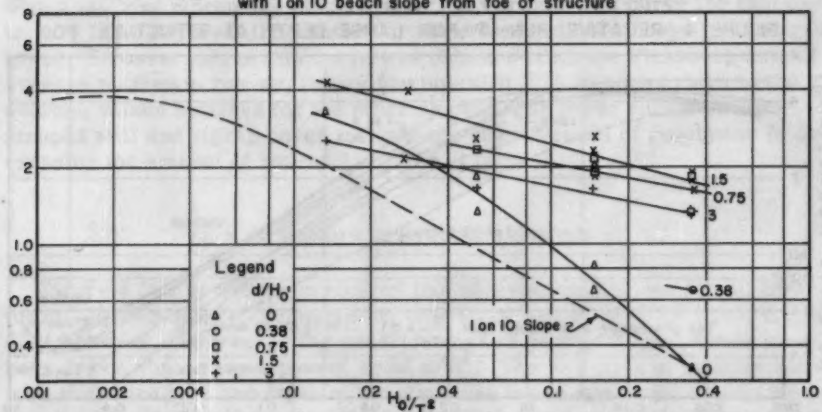
FIG. 3 · RUN-UP AS A FUNCTION OF STRUCTURE DEPTH AND WAVE STEEPNESS



g. Curved wall – Galveston type, with 1 on 10 beach slope from toe of structure



h. Recurved wall – Galveston type with top recurvature added, with 1 on 10 beach slope from toe of structure



i. Step-faced wall 1 on 1½ slope, with 1 on 10 beach slope from toe of structure

FIG. 3 · RUN-UP AS A FUNCTION OF STRUCTURE DEPTH AND WAVE STEEPNESS

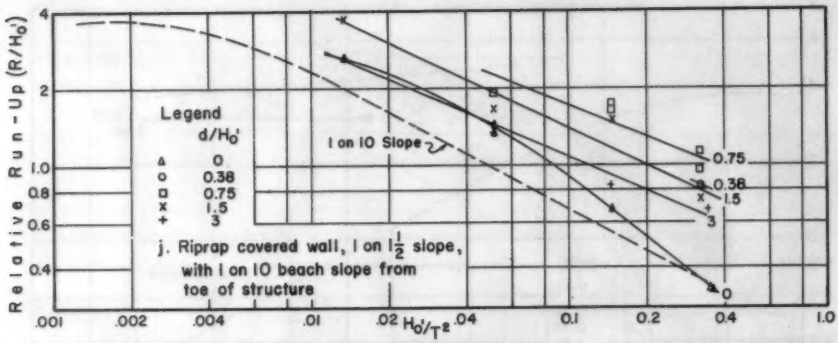


FIG. 3 · RUN-UP AS A FUNCTION OF STRUCTURE DEPTH AND WAVE STEEPNESS

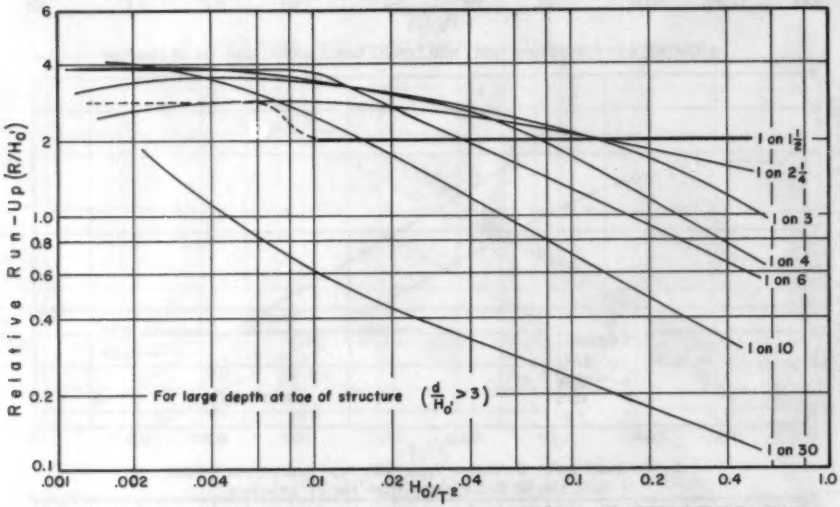


FIGURE 4 · RELATIVE RUN-UP FOR LARGE DEPTH AT STRUCTURE TOE

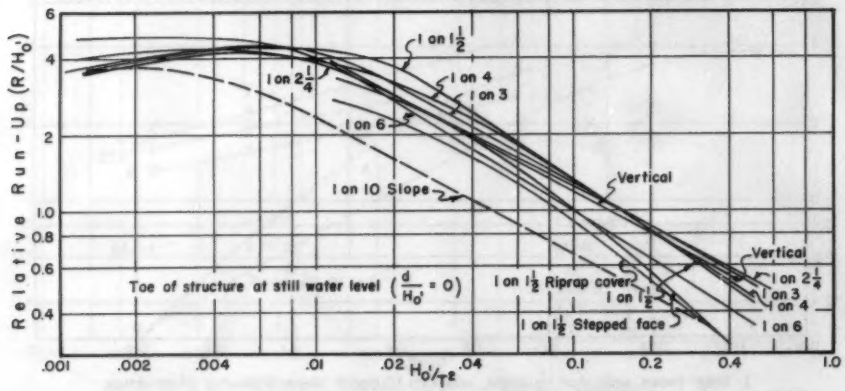


FIGURE 5 · RELATIVE RUN-UP FOR ZERO DEPTH AT STRUCTURE TOE

correspond to those used for the applicable ranges for the Board data.

Figure 4 shows the curves derived for the various slopes tested for conditions of deep water at the structure toe—that is, where, in the laboratory, the structure extended to the full depth of the tank. The points delineating these curves were essentially all for depths equal to or greater than three times the wave height. They are, for the 1 on 1 1/2 through 1 on 6 slopes, identical with the curves shown in Figure 3 for d/H greater than three. The data for the 1 on 10 slope curve are shown in Figure 2. The points establishing the curve for the 1 on 30 slope are not shown, but some 33 points were used to determine the curve and it does not deviate more than ±10 percent from any point. As noted earlier, the scatter was quite small for the gentle slopes (1 on 30, 1 on 10, and 1 on 6) but became quite appreciable as the 1 on 1 1/2 slope was approached. This may also be seen from the plotted points in Figure 3. As is to be expected, the run-up increases as the slope steepens —at least for the steeper waves. A slight decrease in run-up with slope increase is indicated for slopes steeper than 1 on 6 for values of H/T^2 of less than about 0.01, but the scatter in this area was so large as to make accurate determination of a curve extremely difficult. However, this relationship might be expected since with deep water fronting the structure the wave becomes more and more reflected as the slope is steepened, and should approach the value of 2.0 for pure clapotis as the vertical slope is neared. It may be seen that this relationship is indeed approached—and that actually the 1 on 1 1/2 slope has a relative run-up value of 2 for most of the experimental range. The increase of relative run-up for this slope from 2 to 3 at an H/T^2 of about 0.01 is not understood, and it is felt that it is possibly not a true indication, but that the plotted points in this area were in some way biased.

Figure 5 shows the curves derived for the condition of zero depth at the structure toe, with a 1 on 10 beach slope seaward. All curves were obtained from Figure 3. Also shown is the curve for the plain 1 on 10 slope which shows the run-up relation for the beach slope alone, with no structure in place. Again, the run-up increased as slope steepens, but after a slope of about 1 on 3 is reached the exact slope appears to make very little difference. Curves for a vertical wall and for a 1 on 1 1/2 stepped wall and a 1 on 1 1/2 slope with a layer of riprap are also shown. The vertical wall curve for this depth is very little different from those for the steeper slopes though lying slightly lower. However, since this curve was obtained from the Vicksburg data of average maximum run-up, it may be somewhat high in comparison to the average values obtained for the other slopes. The lower curves for the stepped wall and riprap cover indicate the effectiveness of roughness in decreasing the amount of run-up.

SUMMARY AND CONCLUSIONS

Figure 6 is a general summary of the information obtained for all structures. Run-up values are shown for only three values of H/T^2 (0.05, 0.1, and 0.3); however, these cover the general range of practical use. Lines have been drawn connecting points of equal d/H_o'. The variation of relative run-up with structure type and depth at the structure toe is apparent. It may be noted that the frequently used value of 1.5 for relative run-up, while quite adequate for most of the structures tested for the steep waves of many design cases (H/T^2 of about 0.3), is not adequate for many types of structures where waves

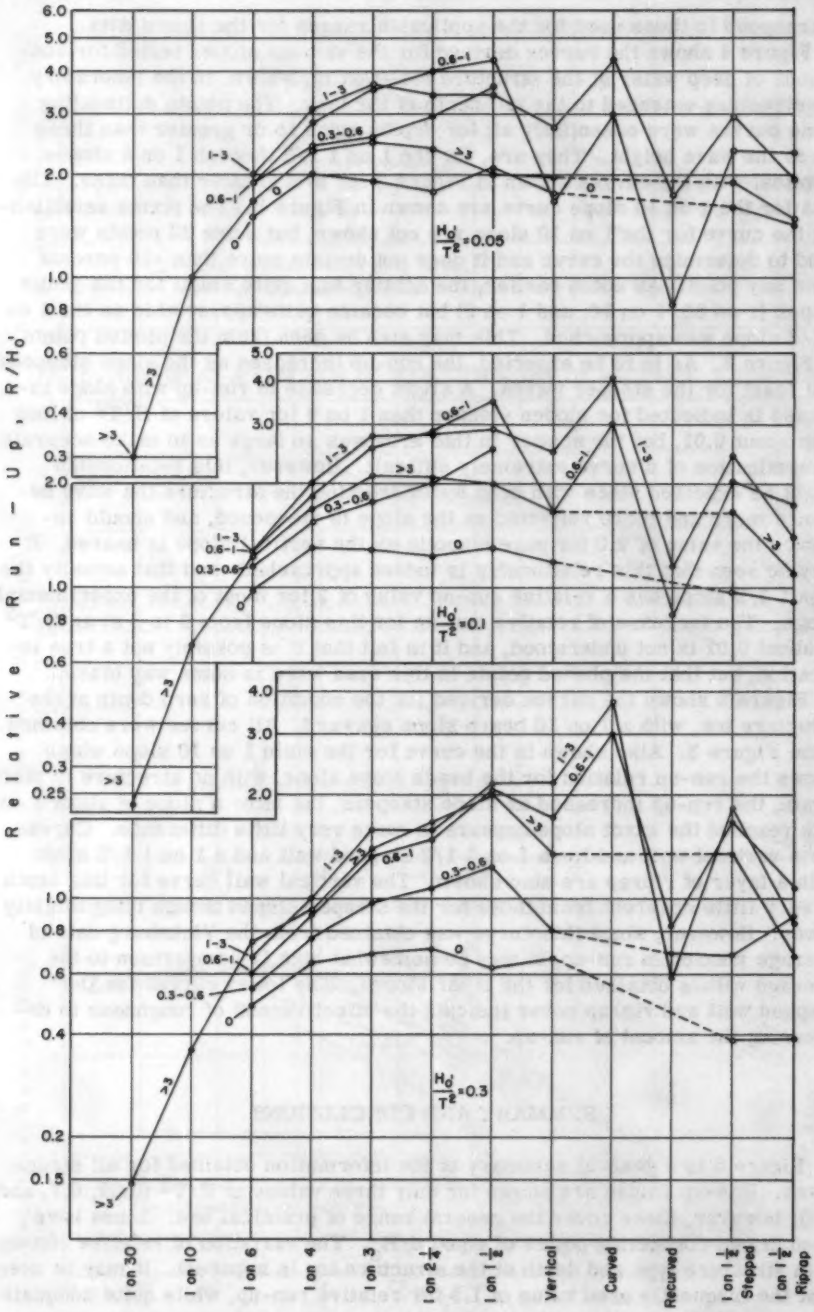


FIGURE 6 · VARIATION OF RELATIVE RUN-UP WITH STRUCTURE TYPE FOR THREE VALUES OF WAVE STEEPNESS

of lower steepness are considered. The vertical wall resulted in lesser run-ups than the slopes steeper than about 1 on 4 for all conditions except that of zero depth at the structure toe, where very nearly the same run-up resulted regardless of slope. This decrease in run-up for the vertical wall may possibly be explained by greater ease of reflection of the uprushing water (if the wave has broken seaward of the structure toe) and the fact that the horizontal momentum of the uprushing water may be applied directly to carry the water forward on the inclined slopes and is there only gradually changed to act in a vertical direction; for the vertical wall, however, it must be changed essentially instantaneously entirely to vertical momentum to carry the water up the wall. For the vertical wall, too, some of the momentum may be changed to a vertically downward direction if the wave breaks directly on the wall. It may be noted also that curved walls apparently represent generally the worst type of wall design when run-up is an important factor. Adding recurvature, however, reduces the run-up considerably—where wave run-up here is determined as the height to which the wall must be raised to prevent overtopping rather than the actual vertical rise of water (for the other structures tested these two definitions are the same). Adding recurvature to a vertical wall would presumably also materially reduce the amount of run-up measured, and hence the crest elevation necessary to prevent overtopping.

In interpreting and using the data presented, the designer must bear in mind that data was obtained for impermeable slopes only, with the partial exception of the single riprap test which involved only a single layer of riprap over an impermeable 1 on 1 1/2 slope. In this test the riprap layer should be regarded almost purely as a roughness parameter rather than one of permeability. Observations indicate that walls of relatively large permeability, as for riprap or rubble mound structures, generally serve to decrease the amount of run-up considerably. Tests presently underway at the Board, however, are indicating that the permeability does have to be relatively large, and that sand beaches, for example, behave (as far as run-up considerations are concerned) essentially the same as solid impermeable structures. The run-up curves presented for the 1 on 10 and 1 on 30 slopes are probably very nearly those for which artificial beaches of these slopes should be designed.

The designer must also remember that the data presented are for structures fronted by a 1 on 10 beach slope only. For cases where the depth at the toe of the structure is several times the wave height, this is not important; indeed, it is probably not especially important even for cases in which the structure depth is only on the order of one wave height or more. For lesser depths, however, greater run-ups may be expected for steeper beach slopes, and lesser run-ups for gentler slopes; the degree of difference will increase as the relative structure depth decreases.

In conclusion, it has been shown that the run-up on a structure depends on the wave steepness (or H/T^2), on the depth at the toe of the structure (unless this depth is large in comparison to the wave height), and, of course, the type and roughness of the structure itself. The curves presented should enable more adequate designs of necessary wall crest elevations, although additional work remains to be done to provide complete data for the full range of pertinent design problems.

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Paper 926 WW 2

JOURNAL
WATERWAYS AND HARBORS DIVISION
Proceedings of the American Society of Civil Engineers

HOUSTON, TEXAS, FLOODWAY

Kenneth Heagy,[1] M. ASCE
(Proc. Paper 926)

SYNOPSIS

The most suitable plan for the flood protection to the city of Houston, Texas, is one which provides for the continued operation of the existing Barker and Addicks Reservoirs and the rectified channel immediately downstream therefrom, and for the clearing, straightening, enlarging, and lining where necessary of the channels of Buffalo, Brays, and White Oak Bayous. Extensive studies were made before this conclusion was reached. Retention and diversion of floodwaters were considered, but the rectification of natural channels proved to be the most desirable and economical.

Description

The city of Houston is located in the center of the Buffalo Bayou watershed. The principal streams passing through the city are Buffalo Bayou and its major tributaries, Brays, and White Oak Bayous. The flood plains of the maximum floods of record on Buffalo, Brays, and White Oak Bayous encompass both urban and rural properties. The municipal development of the city of Houston and adjacent towns comprising the Houston metropolitan area extend within these flood plains and include extensive industrial, commercial and residential properties as well as utilities and transportation facilities. The heart of the city of Houston, situated at the confluence of White Oak Bayou and Buffalo Bayou, has experienced heavy damages to commercial and industrial properties. Extensive residential expansion, since 1945, within the flood plain of Brays Bayou has greatly increased the damage potential from the floods on this stream. The location and extent of the Buffalo Bayou watershed and the locations of Buffalo, Brays, and White Oak Bayous are shown on figure 1.

Note: Discussion open until September 1, 1956. Paper 926 is part of the copyrighted Journal of the Waterways Division of the American Society of Civil Engineers, Vol. 82, No. WW 2, April, 1956.

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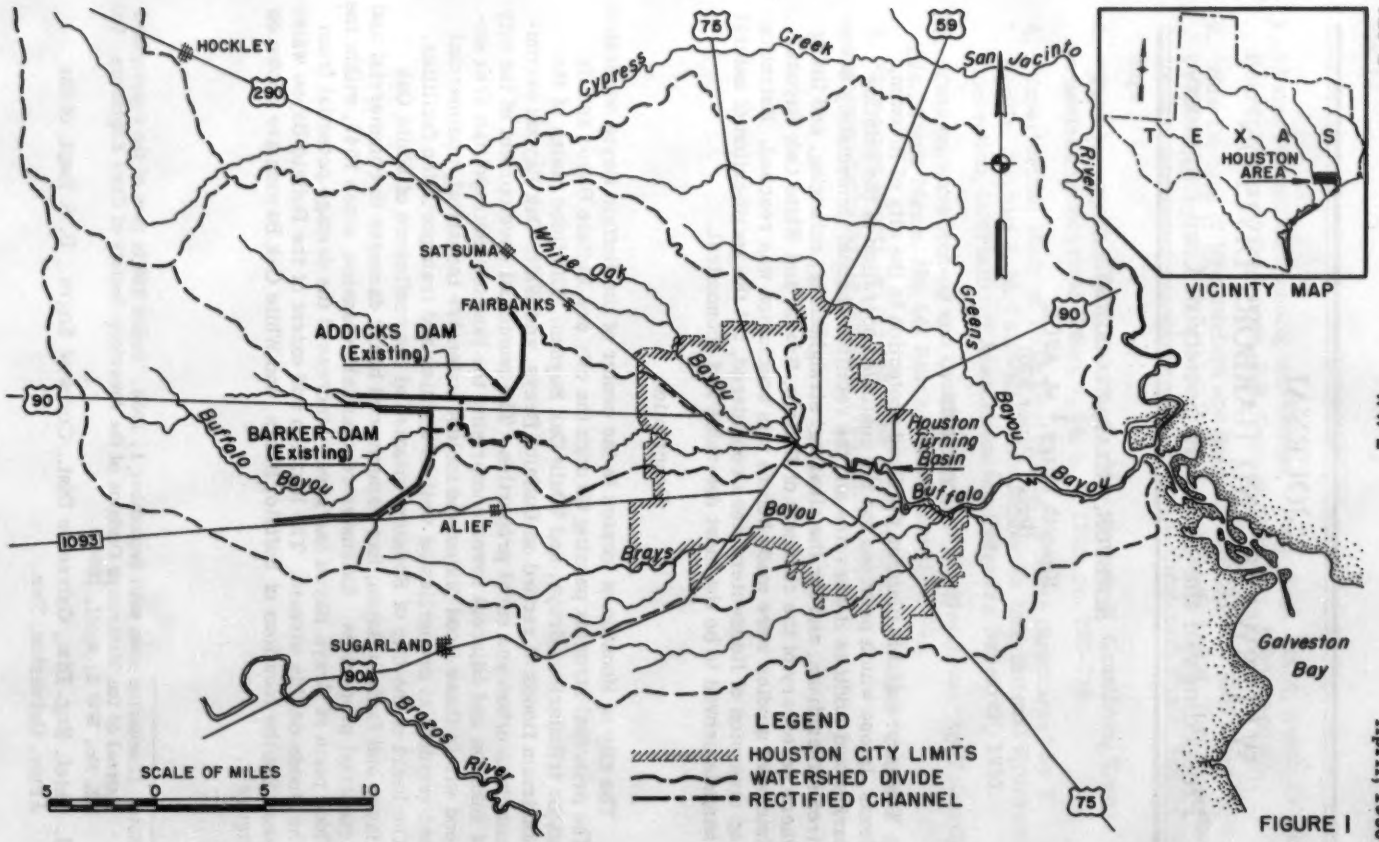

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WW 2

April, 1956

FIGURE I

Channel Flow Capacities

The present flow capacity of the channel of Buffalo Bayou at bankfull stage decreases rapidly from about 30,000 cubic feet per second between the Houston turning basin and the mouth of White Oak Bayou, mile 21.7, to about 25,000 cubic feet per second upstream from the mouth of White Oak Bayou, and thence the channel capacity decreases gradually to about 6,000 cubic feet per second at mile 43.6.

The present flow capacity of the channel of Brays Bayou at bankfull stage is about 12,000 cubic feet per second at the mouth and remains relatively constant to mile 8.7, MacGregor Drive; thence the channel capacity decreases gradually to about 5,900 cubic feet per second at mile 10.8, Old Main Street; 2,500 cubic feet per second at mile 14.6, Willow Waterhole Bayou; and about 1,000 cubic feet per second at mile 19.4, Kegans Bayou.

The present flow capacity of the channel of White Oak Bayou at bankfull stage is about 10,000 cubic feet per second at the mouth and remains relatively constant to mile 1.5, Little White Oak Bayou. Above Little White Oak Bayou the channel capacity decreases gradually to about 6,000 cubic feet per second at mile 4.3, Yale Street; about 3,000 cubic feet per second at mile 14.3, Brickhouse gully; and about 2,000 cubic feet per second at mile 17.3, Cole Creek.

Hydrology

Storms

The major storms which have occurred on the Buffalo Bayou watershed, for which rainfall data are available, together with information regarding the location of the storm centers, the total precipitation, and the duration at the centers, and the average depth over the Buffalo Bayou watershed, are listed in table 1.

Table 1.- Major storms

Period of storm	Storm Center: Location	Duration (hours)	Rainfall (inches)	Average depth over watershed (inches)
May 24-31, 1929	Fairbanks	42	12.95	7.9
Dec. 6-8, 1935	Near Satsuma	34	20.80	11.7
Sept. 23-25, 1941	Sugarland	48	9.55	(1)
Nov. 1-3, 1943	Near Alief	25	12.20	7.9
Aug. 27-30, 1945	Near Hockley	30	20.06	11.6

1 Not determined.

Floods

Historical records indicate that floods occurred on Buffalo Bayou and its tributaries in 1854, 1875, 1879, 1907, and 1929. The city of Houston was founded in 1835 and, based on testimony and records of local interests, the maximum known flood on Buffalo Bayou, White Oak Bayou, and Little White Oak Bayou occurred in December 1935. During this flood some overflow occurred from White Oak Bayou into Buffalo Bayou, and considerable overflow occurred from Buffalo Bayou into Brays Bayou. The peak discharge of the

December 1935 flood on Buffalo Bayou, White Oak, and Little White Oak Bayous are shown in table 2.

Table 2.- December 1935 flood

Stream	Location	River mile	Peak discharge (cubic feet per second)
Buffalo Bayou	Eureka cutoff	29.4	40,030
Buffalo Bayou	Lockwood Dr.	18.4	52,750
White Oak Bayou	Railroad bridge west of Stude Park	3.4	14,750
Little White Oak	Sylvester St.	3.8	4,950

The maximum known stages along Brays Bayou between mile 14.2 and mile 2.8 were produced by the flood of August 1945; and over the remainder of the bayou by the flood of May 1929. Flood flows on Buffalo, White Oak, and Brays Bayous have been measured by the United States Geological Survey since 1936. The floods of record in 1941, 1943, and 1949 were of damaging nature on Brays Bayou. Table 3 shows the maximum flood discharges during the period of record of the United States Geological Survey stream gaging stations.

Table 3.- Maximum flood discharge of U.S. Geological Survey record, 1936-49

Stream	Locality	River mile	El. mean sea level	Peak discharge (cubic ft. per second)	Date
Buffalo Bayou	Addicks	46.6	80.93	11,200	Aug. 29, 1945
Buffalo Bayou	Waugh Dr.	24.7	33.83	10,900	Aug. 30, 1945
White Oak Bayou	Yale St.	4.2	38.37	8,600	Nov. 2, 1943
Brays Bayou	Old Main St.	10.8	46.70	8,120	Nov. 2, 1943
South Mayde Creek	At Addicks Dam	1.3	89.98	2,250	Apr. 23, 1949
Buffalo Bayou	At Barker Dam	49.8	90.10	2,840	Aug. 30, 1945

Frequency of Flooding

Table 4 shows the approximate floodstage discharges at selected points on Buffalo, White Oak, and Brays Bayous and their frequency of occurrence. Frequencies are based on the assumption that Barker and Addicks are not in existence and that runoff occurs under 1950 watershed and channel conditions.

On Brays Bayou, at Old Main Street, the stage at which flooding begins, under 1950 conditions, represents an estimated discharge of 5,900 cubic feet per second. However, during the period of record, flooding has occurred at less discharge because of varying channel conditions. As shown in table 4,

Table 4.- Frequency of flood-stage discharges

Station	Location	Discharge in cubic feet per second	Frequency in years
Buffalo Bayou	Above Waugh Dr.	23,000	7.25
White Oak Bayou	Below Brickhouse Gully	3,000	0.5
White Oak Bayou	Yale St.	6,000	2.75
Brays Bayou	Old Main St.	5,900	1.25
Brays Bayou	Below Kegans Bayou	1,000	0.25

the frequency of occurrence of flood-stage at Old Main Street is about once each year. The maximum discharge of record at Old Main Street, shown in table 3, is 8,120 cubic feet per second which is only 1.4 times the estimated floodstage discharge.

Plans Considered

Following the destructive flood of December 1935 which caused the loss of 8 lives, damaged property in the city of Houston to the extent of about $2,500,000, and severely hindered navigation in the Houston Ship Channel, a Federal flood control project for Buffalo Bayou was authorized by the River and Harbor Act of June 20, 1938 and the Flood Control Act of August 11, 1939. This project authorized improvement of Buffalo Bayou and its tributaries above the Houston Ship Channel turning basin to provide for the control of floods, the protection of the city of Houston from flood damages, and the prevention of the deposit of silt in the turning basin by means of detention reservoirs, enlargement and rectification of channels, the construction of control works and any diversions which may be found advisable.

Under this authorized project, the Corps of Engineers and the Harris County Flood Control District, the State agency representing local interests, in 1940 formulated a joint general plan of development for the detail design and construction of flood-control works on Buffalo Bayou. The basic features of this joint plan, with subsequent minor revisions, were:

a) Construction of the White Oak detention reservoir and the north diversion canal and appurtenant works to prevent discharging flood flows from upper White Oak Bayou through the city of Houston.

b) Construction of the Barker and Addicks Reservoirs in the vicinity of Addicks to control the runoff from upper Buffalo Bayou and the south diversion canal, including 7.4 miles of channel rectification, from the twin reservoirs to Galveston Bay to prevent this runoff from passing through the city of Houston.

c) Removal of obstructions in the channel of Buffalo Bayou within the city of Houston.

d) Protection of the floodway areas against further encroachment by the establishment and enforcement of building limit lines upon existing streams and the prevention of dumping of waste materials upon the banks of the existing streams within the building limit lines.

The diversion plan (see figure 3) was considered desirable because at that

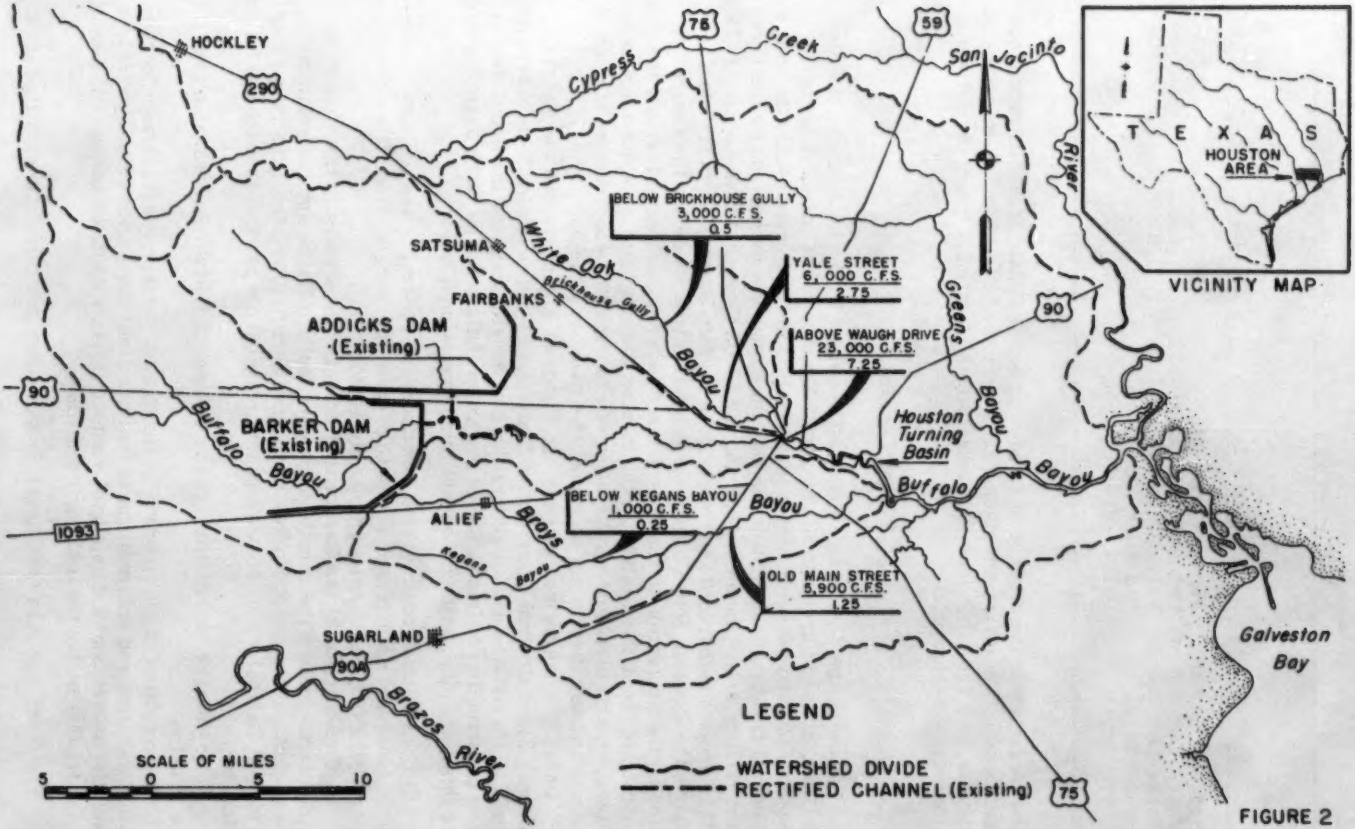

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FIGURE 2

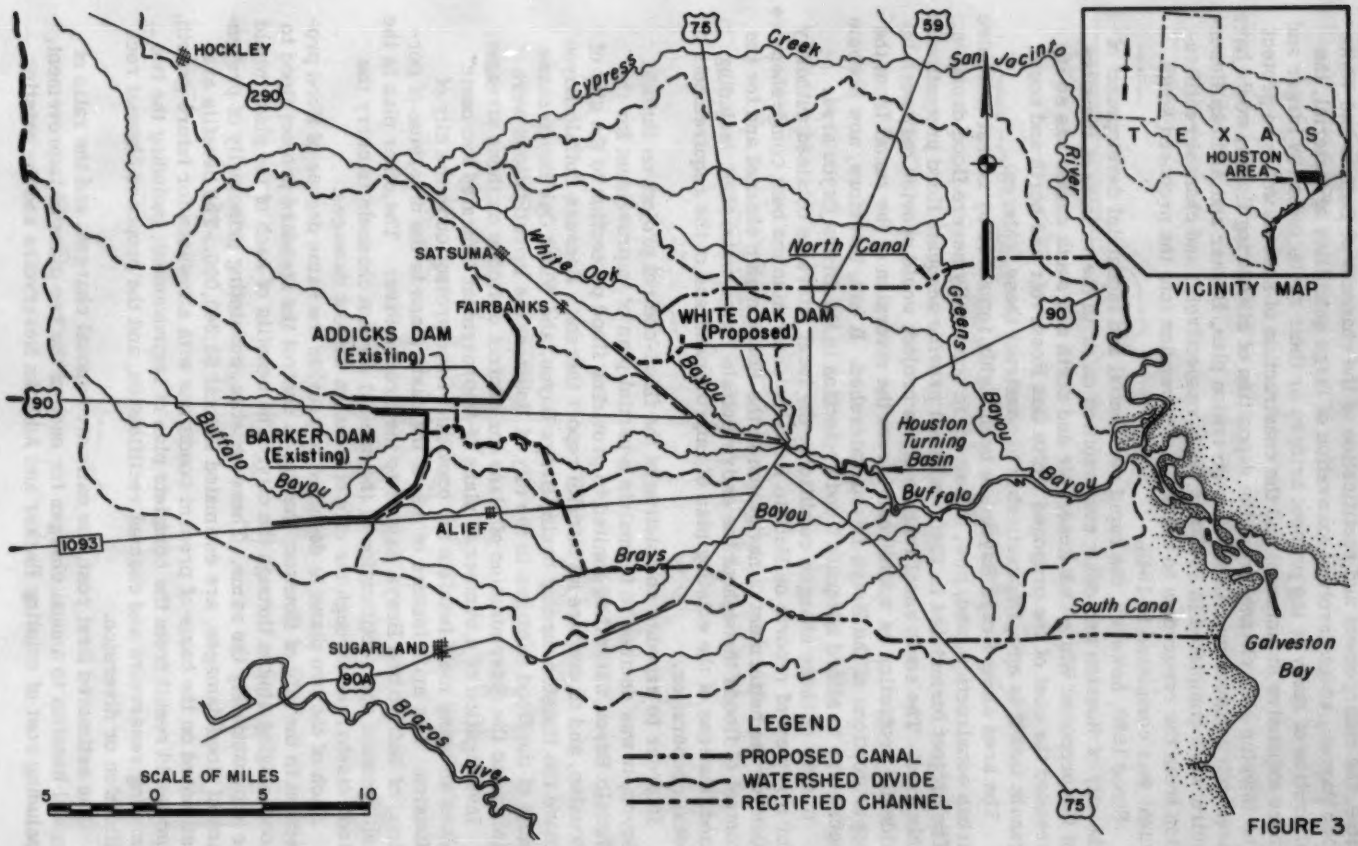
HOCKLEY
290
75
59
Cypress Creek
San Jacinto River
TEXAS
HOUSTON AREA
VICINITY MAP
SATSUMA
White Oak Bayou
North Canal
FAIRBANKS
ADDICKS DAM (Existing)
WHITE OAK DAM (Proposed)
Greens Bayou
90
BARKER DAM (Existing)
Buffalo Bayou
Houston Turning Basin
ALIEF
1093
Brays Bayou
South Canal
Galveston Bay
SUGARLAND
90A
Brazos River
SCALE OF MILES
5 0 5 10
LEGEND
PROPOSED CANAL
WATERSHED DIVIDE
RECTIFIED CHANNEL

FIGURE 3

time, the enlargement and rectification of the channels of Buffalo and White Oak Bayous, which involved excavation of large quantities of material, the alteration of many of the present bridges or their replacement by larger and more expensive structures, and the construction of special works to protect the Houston ship channel from the deposition of silt during floods, would have been more expensive. Under this diversion plan, Barker and Addicks Reservoirs were completed in 1945 and 1948, respectively, and channel rectification from the reservoirs to the point of diversion into the proposed south canal was completed in 1948.

Since 1940, however, the rapid residential and industrial development of the city of Houston and other communities on or in the vicinity of the sites of the proposed White Oak Reservoir and north and south canals has so increased the cost of the proposed White Oak Reservoir and north and south canals that it is now, impracticable to construct these features.

The area along Brays Bayou has been highly improved by recent extensive urban construction, and, now, is subject to potentially severe flood damages. The project formulated in 1940 would not provide adequate flood protection to this area. The south canal feature of the project would provide only such incidental protection as would result from the diversion of the runoff from the upper portions of the Brays Bayou watershed. It has, therefore, now become necessary to afford adequate flood protection to the Brays Bayou area.

In view of these changed conditions, the local interests obtained authority for a review of reports on Buffalo Bayou to determine the best comprehensive plan for the betterment of navigation in the Houston ship channel and for the control of floods throughout the entire Buffalo Bayou watershed, including modifications of the existing plan of improvement and of the requirements of local cooperation.

In order to expedite completion of the flood-control project on Buffalo Bayou, it was decided to formulate a partial plan of improvement for the Buffalo Bayou watershed limited to providing flood protection to the city of Houston, and to prepare an interim report thereon. Because Buffalo Bayou above the Houston turning basin, Brays Bayou, and White Oak Bayou cause most of the flood damages in the city of Houston, the investigations were limited to the determination of plans for control of floods on those streams.

Investigation of a number of plans of improvement indicated two basic plans as being most feasible for providing flood protection to the city of Houston. The main feature of one of the basic plans is the diversion of portions of Buffalo and Brays Bayous to the Brazos River. The other plan is the enlargement and rectification of the natural stream channels to carry the flood discharges through the city of Houston without damages.

Each of the two plans is designed to provide the same degree of flood protection to the city of Houston; that is, to control the standard project flood to nondamaging stages through the city. The benefits of each of the plans would be approximately the same. These benefits, consisting principally of prevention of flood damages, are estimated to total $3,345,000. The benefits are estimated on the basis of present conditions with allowance for future growth, and would result from the complete plan of improvement, including the two existing reservoirs and channel rectification, and the proposed channel rectification or diversion.

The estimated first cost, the estimated annual charges, and the ratio of annual benefits to annual charges for each of the two plans of improvement, including cost of existing Barker and Addicks Reservoirs and the existing

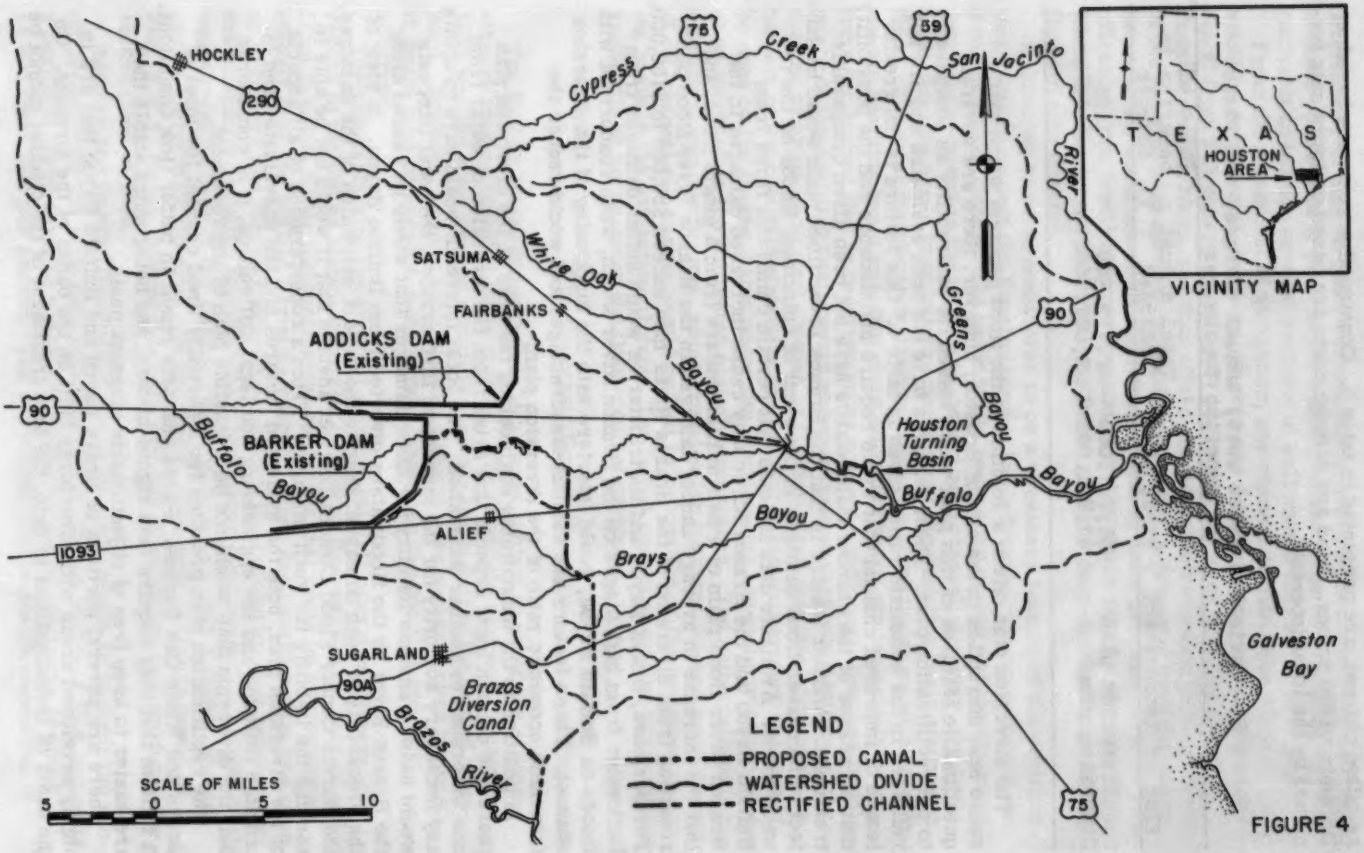

FIGURE 4

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rectified channel, are presented in table 5. Construction costs are based on December 1950 prices. Land and damage costs are based on appraisals furnished by the local interests.

Table 5.- Estimated first cost, annual charges, and ratio of benefits to charges

Plan of improvement	First cost	Total annual charges	Ratio of benefits to charges
Rectification plan	61,761,000	2,775,300	1.21
Diversion plan	62,861,000	2,877,700	1.16

The diversion plan offers a solution to the flood problem which would cause less disruption in the city of Houston; however, there are several questionable features of this plan which lessen its desirability as compared to the rectification plan. These features have not been evaluated and are not reflected in the economic ratios given in table 5. One feature is the greater length of improved channel that would require maintenance and the possibility that all phases of the channel maintenance have not been given comparable treatment. Another feature is that the Brazos River flood plain would be subject to increased flood damages in the event of coincident floods on the two watersheds. Available data indicate that certain coincident flows from Buffalo Bayou and the Brazos River may cause increased damages in the Brazos River flood plain of a half million dollars from a single flood, and that the increase in average annual damages in the Brazos River flood plain, resulting from diversion of the Brazos River may exceed $50,000 to $100,000. Furthermore, Brays Bayou and its tributaries would suffer damages from backwater from high stages on the Brazos River which, when concurrent with floods on Buffalo Bayou, would interfere with the functioning of the diversion channel. These factors are serious disadvantages and would reduce the favorable economic ratio of the diversion plan.

In addition to the unfavorable engineering features of the diversion plan there are certain legal aspects that arise from the diversion of water from one watershed to another watershed. The local interests would have to obtain any necessary authority for the diversion; furthermore, the local interests would have to assume liability for flood damages that would be caused along the Brazos River by the floodwaters diverted from Buffalo Bayou. In view of the probability of such damages, despite the lack of estimates of the damages, the Harris County Flood Control District advised that it would not be able to assume the liability for such damages. From a consideration of all aspects of the diversion plan, both the evaluated features and the unevaluated and intangible features and the engineering and legal difficulties, it is considered that the diversion plan would not be a feasible plan of improvement.

The rectification plan provides for a partially lined channel for most of Brays and White Oak Bayous. Paved channels result in better flow conditions. It follows that they require less rights-of-way, and being more stable they are easier to keep free of objectionable stagnant pools.

There are several portions of Brays Bayou and Buffalo Bayou that are in highly developed areas with structures built on the banks of the streams. On the basis of investigations to date, the best treatment of the channel cannot be

determined. It may be more economical to provide vertical sheet-pile walls at these points than to provide for sloping sides. (The estimates of cost are sufficient to include several sections of wall should they prove necessary.)

From the standpoint of navigation, any channel rectification work by itself would be detrimental; however, Barker and Addicks Reservoirs control the runoff from 279 square miles or 57 percent of the area draining into the Houston turning basin, and thus afford considerable reduction to the currents in the Houston ship channel during floods. Also, a proposed desilting basin immediately upstream from the Houston turning basin provided with the rectification plan, would reduce the quantity of silt which may be carried from White Oak Bayou and upper Buffalo Bayou into the deep-draft channel of the Houston ship channel.

A desilting basin is considered to be a necessary feature of the rectification plans to protect the Houston turning basin from excessive sediment deposition during floods. The basin would reduce the quantity of maintenance dredging required in the turning basin and ship channel; however, the sediment deposits would have to be removed from the desilting basin after each flood. The total maintenance dredging would be about the same with or without the desilting basin and, therefore, probably would not materially differ from the amount that is required under present conditions. Because maintenance of the desilting basin would reduce the necessary maintenance of the turning basin an equivalent amount, it is considered that this work ought to be part of the cost of maintaining the existing navigation project and should be done by the United States under the Houston ship channel navigation project at no increase in the estimated cost of maintenance. The authorization of the existing navigation project, which provides for construction and maintenance of off-channel silt basins, would permit incorporation of the proposed desilting basin in the navigation project. The initial cost of providing the desilting basin will be borne under the flood-control project.

The Reservoir Design Storm

The Buffalo Bayou watershed is in an area subject to all of the circumstances making possible large storms. The Westfield storm of December 1935 was the most intense storm to visit the basin during the period of record. However, had the 1935 Westfield storm been centered over the basin, it would have produced a more severe flood than the one that actually occurred.

The storm showing the greatest depth of rainfall over a large area, of record in the United States, occurred in 1899 at Hearne, Texas, only 90 miles from Houston, under meteorological conditions that could be approximated closely over the Buffalo Bayou watershed. After due consideration by Corps of Engineers and Weather Bureau personnel, the conclusion was reached that the maximum probable storm which might occur over the Buffalo Bayou basin was a transposition of the Hearne storm of June 28 - July 1, 1899. Should such a storm visit the area, the average rainfall over the basin would be in excess of 27 inches, almost twice the average of 15 inches that produced the record flood of 1935.

Addicks and Barker Reservoirs are of such magnitude as to limit the runoff produced by the maximum probable storm (design storm of 31.4 inches in a period of three days) to a maximum total regulated discharge of about 15,000 cubic feet per second. The ultraconservative design capacities of

these reservoirs were considered justified since failure of either dam might result in loss of life and damage far in excess of the cost of these structures.

Determination of Standard Project Flood

In order to achieve more uniform results in the hydrological investigations of its field agencies, the Corps of Engineers has developed the concept of a Standard Project Storm and a Standard Project Flood for its flood control investigations. A Standard Project Storm for a particular drainage area should represent the most severe flood-producing rainfall quantity-intensity sequence relationship and areal distribution of any storm that is considered reasonably characteristic of the region in which the drainage basin is located, giving due consideration to the run-off characteristics of the basin.

The Standard Project Flood is the run-off from the Standard Project Storm. The Standard Project Flood represents a practical measure of the "flood potentiality" of a particular drainage basin, corresponding to storms and run-off conditions observed in the region on a sufficient number of occasions to demonstrate that a distinct danger exists of such a flood occurrence. The Standard Project Flood reflects a generalized analysis of flood potentialities in a region, as contrasted to an analysis of limited flood records at the specific locality that may be misleading because of the inadequacies of records or abnormal sequences of hydrologic events. The statistical probability of occurrence of this standard Project Flood is not of primary importance. The principal purposes of the Standard Project Flood are to:

a) Serve as a "standard" against which the degree of protection finally selected for the project may be judged and compared with protection provided at other projects of a similar nature.

b) Represent the flood discharge that should be selected as the design flood for the project, or approached as nearly as practicable in consideration of economic or other governing limitations, if an unusually high degree of protection is justified by hazards to life and high property values within the area to be protected.

The Standard Project Flood used in the present investigation of Buffalo Bayou is derived from an over-all study, made by the Corps of Engineers, of all recorded major storms in the United States east of 105° longitude for small drainage basins of 1,000 square miles or less. The 105th meridian crosses the extreme western tip of the State of Texas and Buffalo Bayou therefore falls within the area encompassed by this study. The rainfall criteria used in the over-all study are based primarily on an analysis of major convective-type storms and relate to a total storm duration period of 24 hours. The average depth over an area of 200 square miles for a duration period of 24 hours was used as the unit for comparing and correlating the storms.

The average depths of 24-hour rainfall over an area of 200 square miles for all storms that have been investigated to date were plotted in their geographical positions. Generalized isohyets representing maximum possible 24-hour rainfall over 200 square miles were obtained from the U. S. Weather Bureau (see figure 5) and superimposed over this map. Studies of the relationship between maximum possible rainfall and the major storms of record indicated that, in general, 50 percent of maximum possible rainfall includes all but about 15 percent of the major storms of record. Accordingly, 50

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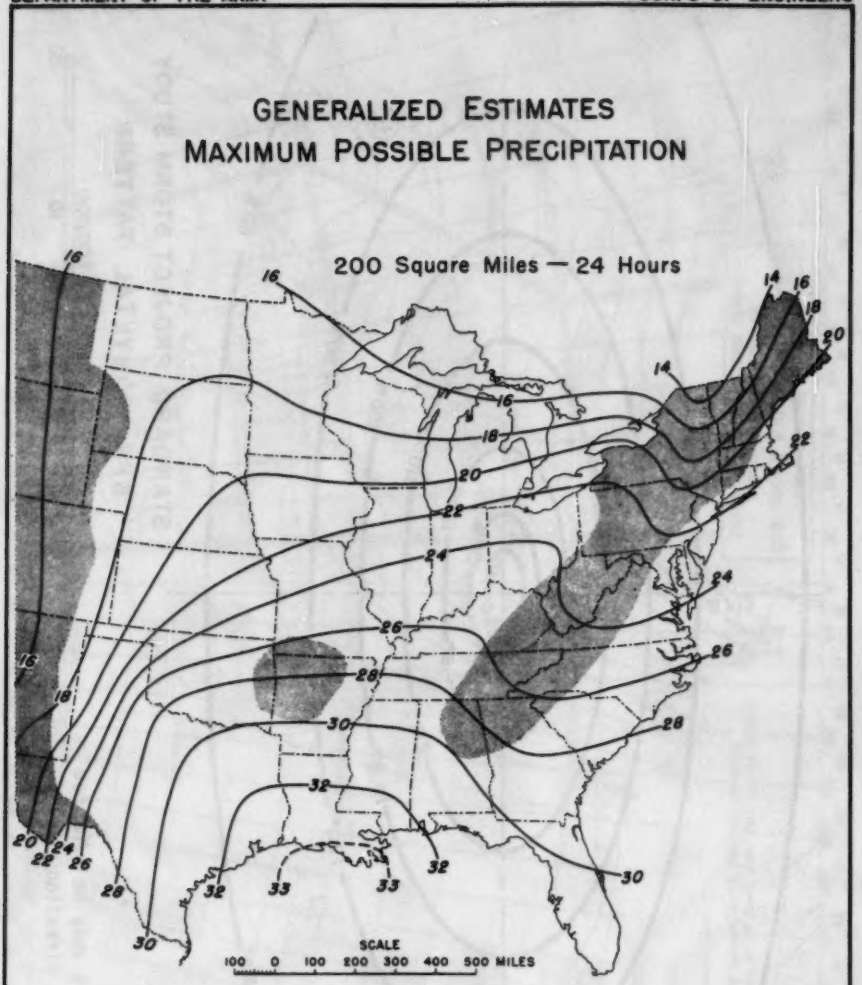

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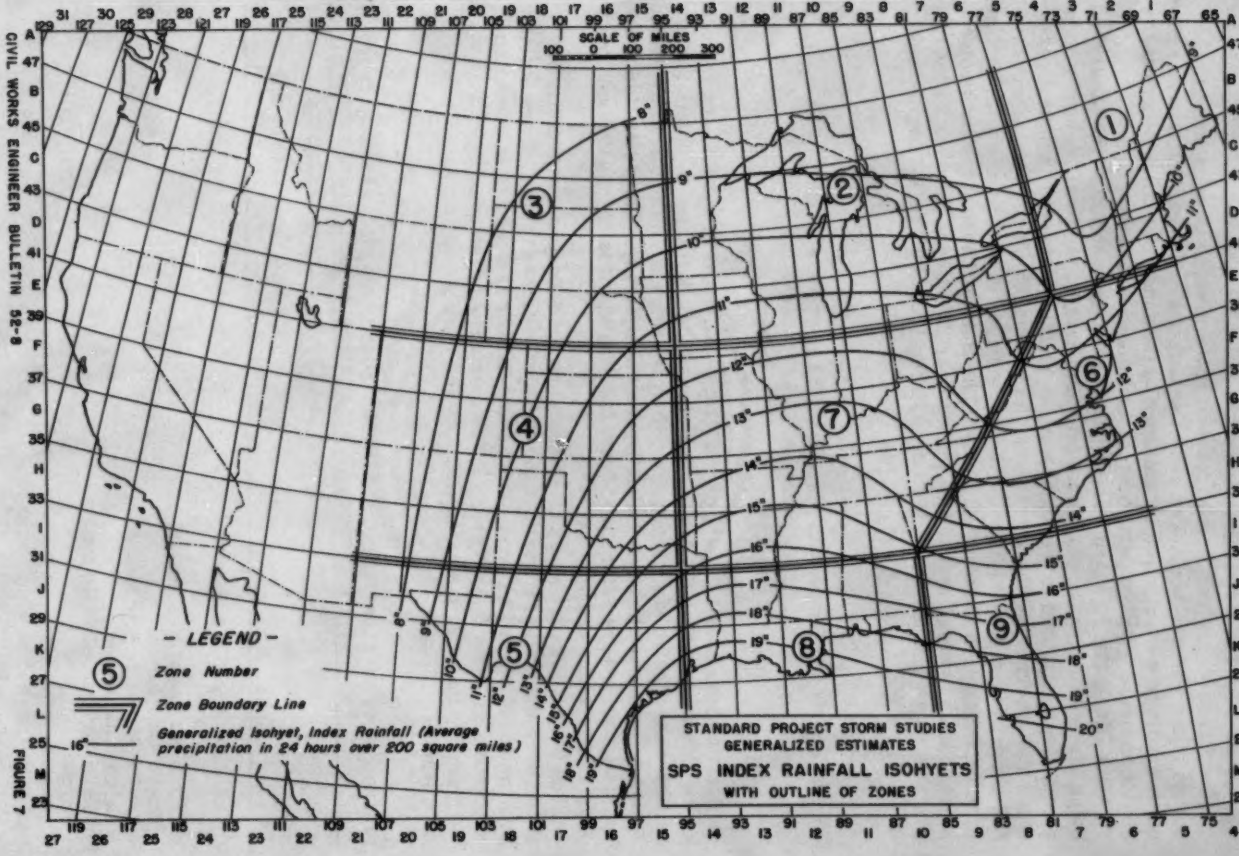
CIVIL WORKS ENGINEER BULLETIN 52-8 FIGURE 5

CORPS OF ENGINEERS U.S. ARMY

CIVIL WORKS ENGINEER BULLETIN 52-8 FIGURE - 6


SCALE OF MILES
100 0 100 200 300
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Zone Boundary Line
Generalized Isohyet, Index Rainfall (Average precipitation in 24 hours over 200 square miles)
STANDARD PROJECT STORM STUDIES
GENERALIZED ESTIMATES
SPS INDEX RAINFALL ISOHYETS
WITH OUTLINE OF ZONES
CIVIL WORKS ENGINEER BULLETIN 52-8
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FIGURE 7

percent of the maximum possible rainfall in the vicinity under consideration was adopted for the Standard Project Storm.

The Standard Project Storm isohyetal pattern which is being used in the design of the Houston project is shown as figure 6. The rainfall values shown on this pattern were derived by multiplying the index rainfall for the locality shown on figure 7 by the percentages shown on the pattern.

After fitting the Standard Project Storm over the section of the watershed being studied to give the maximum peak discharges, the total 24-hour storm volume is determined in the usual way, by planimetering the isohyetal patterns and determining the average depth of storm rainfall. This storm rainfall depth is then divided into four 6-hour periods in accordance with percentages determined in the over-all study. The Buffalo Bayou Standard Project Storm has an average depth of 19 inches over 200 square miles in 24 hours. For this depth, the time distribution of rainfall for the four 6-hour periods is as follows:

First period:	9.5 percent
Second period:	20.1 percent
Third period:	56.7 percent
Fourth period:	13.7 percent

Infiltration losses of 1.0 inch for the first 6-hour period and 0.6 inch for each of the three remaining 6-hour periods were then subtracted to obtain the rainfall excess. The rainfall excess was then developed into the Standard Project Flood by means of the Snyder Unit Hydrograph Method. The coefficients used in this formula were determined from the reproduction of actual floods on Buffalo Bayou and tributaries.

The peak flows that would be produced by the Standard Project Storm fitted over the principal parts of the Buffalo Bayou watershed, under existing and improved conditions with Addicks and Barker Reservoirs in operation, are shown in Table 6 and Table 7. For comparison, the peak flows that would be produced under present conditions by the 1935 storm increased 50% are also shown.

Table 6.- Peak flows produced by standard project storm and by 1935 storm increased 50%, under existing conditions

Location	Peak flows in c.f.s.	
	Standard Project Storm	1935 storm increased 50%
White Oak Bayou at mouth	25,200	24,700
Buffalo Bayou above mouth of White Oak Bayou	26,400	22,500
Buffalo Bayou below mouth of White Oak Bayou	49,200	46,200
Buffalo Bayou below Brays Bayou	74,000	70,700
Brays Bayou below Kegans Bayou	16,200	17,800
Brays Bayou at Old Main St.	25,000	24,600
Brays Bayou at mouth	31,200	30,700

Table 7.- Comparison of peak flows of standard project flood with diversion and channel rectification plans in operation

Location	Peak flows in c.f.s.	
	Diversion plan	Channel rectification plan (a)
White Oak Bayou at mouth	12,400	27,700
Buffalo Bayou above mouth of White Oak Bayou	27,600	31,300
Buffalo Bayou below mouth of White Oak Bayou	34,300	55,400
Buffalo Bayou below Brays Bayou	52,700	87,400
Brays Bayou below Kegans Bayou	0	16,200
Brays Bayou at Old Main St.	15,800	28,000
Brays Bayou at mouth	23,000	35,700

(a) Peak flows are for improved channel conditions.

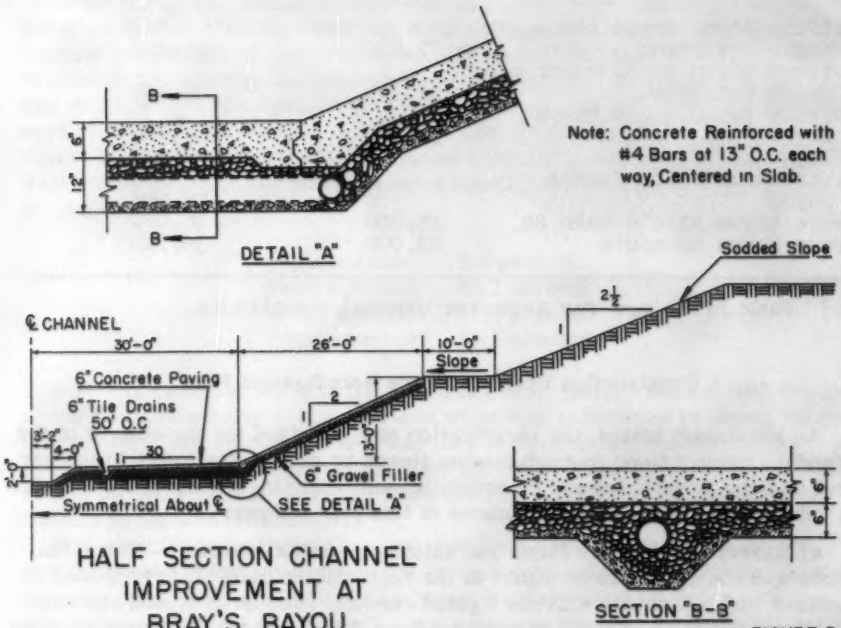
Construction Features of the Rectification Plan

As previously stated, the rectification plan provides for the control of the standard project flood to nondamaging stages by detention storage in Barker and Addicks Reservoirs and by enlarging and rectifying the stream channels. A detailed description of the features of this plan follows:

a) Barker and Addicks Dams and existing rectified channel. - These features are considered to be a part of the rectification plan. It is proposed to operate each reservoir with the 3 gated conduits remaining closed and with all discharge through the 2 ungated conduits during passage of floods through the reservoirs. The combined floodpeak discharge from the two reservoirs would amount to approximately 6,700 cubic feet per second for the standard project flood. The existing rectified channel has sufficient capacity to carry the standard project flood and would not be modified.

b) Enlargement and rectification of Buffalo Bayou. - It is proposed to enlarge and rectify Buffalo Bayou from the turning basin of the Houston ship channel, mile 16.0, to the lower end of the existing channel rectification, mile 43.6. The proposed rectified channel would be about 20 miles long, trapezoidal in cross section, and with sodded banks with slopes of 2 1/2 to 1, except in reaches where adjacent development is such that channel paving or the flood walls is more feasible to obtain the necessary capacity. This plan includes a desilting basin just above the turning basin to reduce the amount of silt entering the turning basin and the Houston ship channel. The proposed basin would have a bottom width of 300 feet at elevation -25 feet, mean sea level, and length of 686 feet. In addition it is proposed to construct erosion-control works in the channel above the turning basin.

c) Rectification of Brays Bayou. - It is proposed to enlarge and rectify Brays Bayou from its mouth to Westheimer Road, mile 25.5. The proposed channel would be 25.5 miles long and trapezoidal in cross-section. Concrete-channel lining will be used on the lower portions of the slopes and the bottom of the channel from tide water, mile 4.4, to Kegans Bayou, mile 19.4. The



HALF SECTION CHANNEL IMPROVEMENT AT BRAY'S BAYOU

FIGURE 8

side slopes in the tidal section and from Kegans Bayou to the upper end of the improvement, mile 25.5, will be sodded with slopes of 2 1/2 to 1. Figure 5 shows a typical section of the partial lined channel.

d) Rectification of White Oak Bayou. - It is proposed to rectify White Oak Bayou from its mouth to the Burlington-Rock Island Railroad bridge, mile 13.5. The proposed channel would be about 8.9 miles long and trapezoidal in cross-section. The plan will provide for concrete-channel lining except that the upper portions of the slopes would be sodded. Lining is considered necessary to prevent excessive scouring of the channel bed and slopes.

e) Changes in utilities. - The proposed channel enlargement and rectification plan will necessitate changes in 5 railroad bridges, 9 highway bridges, and in some utilities adjacent to or across Buffalo Bayou; in 8 railroad bridges, 19 highway bridges, and in some utilities adjacent to or across Brays Bayou; and in 1 highway bridge across White Oak Bayou.

f) Miscellaneous. - The estimates of cost for the proposed plans of improvement include allowances to provide for any erosion prevention works which may prove necessary in those channels where no protection was provided.

ACKNOWLEDGMENTS

The writer wishes to acknowledge that much of the descriptive matter and tables of computations for this paper were taken from Corps of Engineers reports prepared under his general supervision by members of the Planning and Reports Branch, Engineering Division, Galveston District. References used were:

Interim Report on Buffalo Bayou and Tributaries, Texas, which is published in part in House Document No. 250, 83d Congress, 2d Session.

Report on Houston Ship Channel and Buffalo Bayou, Texas, which is published in part in House Document No. 456, 75th Congress, 2d Session.

Corps of Engineers Civil Works Engineer Bulletin 52-8.

JOURNAL
WATERWAYS AND HARBORS DIVISION
Proceedings of the American Society of Civil Engineers

TRINITY RIVER FLOOD CONTROL PROJECT*

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(Proc. Paper 927)

SYNOPSIS

A Federal project consisting of four reservoirs and two floodway improvements on the Upper Trinity River, Texas, is described. The reservoirs and floodway give protection to agricultural lands and to the urban areas of Fort Worth and Dallas. The reservoirs are multipurpose, containing storage for municipal and industrial water supplies.

The Trinity River Basin lies in the eastern half of the State of Texas, between 29° 46' and 33° 44' north latitude and 94° 40' and 98° 43' west longitude. The basin is situated entirely within the State of Texas and is bounded on the north by the Red River Basin; on the east by the basins of the Sabine and Neches Rivers; and on the west and south by the basins of the Brazos and San Jacinto Rivers. The Trinity River Basin is relatively long and narrow. Its maximum length is about 360 miles and its maximum width is about 100 miles near the headwaters. The basin has a total area of about 17,845 square miles. The drainage area above Rosser, Texas (just downstream from the confluence with the East Fork) is 8,162 square miles and this area is considered as the upper Trinity watershed. The upper watershed is shown on Plate 1.

The importance of the Trinity River has long been recognized by Texans. Over 100 years ago the river was utilized for transportation by the early settlers. In 1841 the Congress of the Republic of Texas authorized W. S. Peters to colonize a large area in North Texas. As a result of this authority, pioneer settlers from the states east of the Mississippi River came into the upper part of the Trinity River Valley. In 1841, John Neely Bryan built a cabin on

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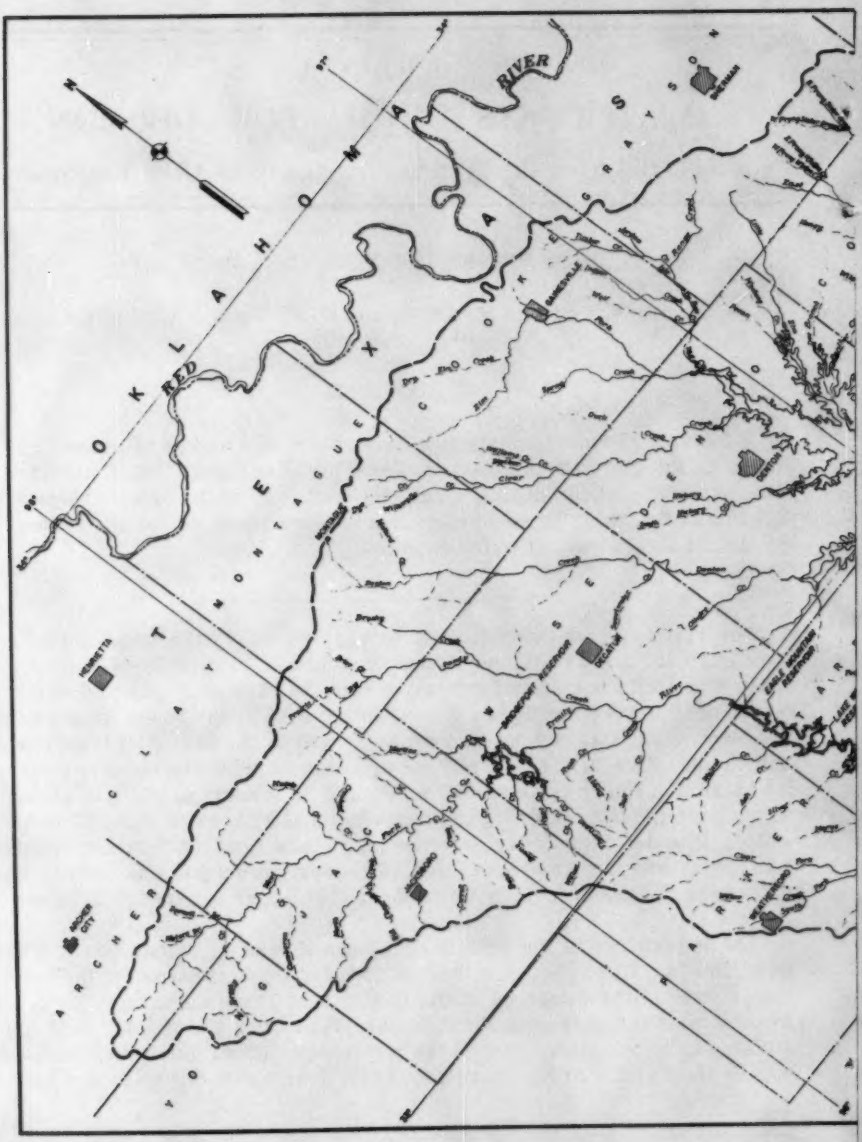
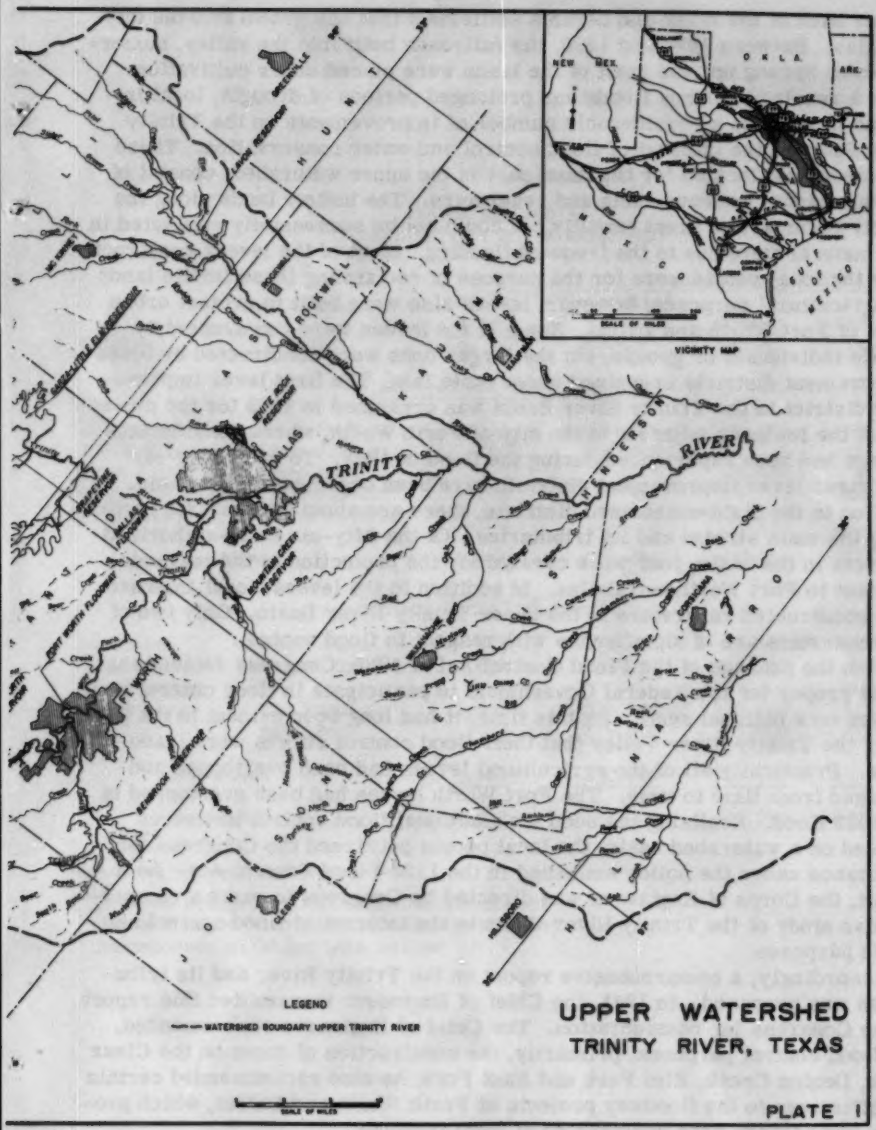

OKLAHOMA
TEXAS
RED RIVER
MONTAGUE
ARCHER
WICHITA FALLS
GRAHAM
JACKSBORO
BRIDGEPORT RESERVOIR
EAGLE MOUNTAIN RESERVOIR



UPPER WATERSHED
TRINITY RIVER, TEXAS

PLATE 1

the left bank of the river and began a settlement that has grown into the city of Dallas. Between 1870 and 1890, the railroads built into the valley, numerous towns sprang up, and most of the lands were placed under cultivation.

As a result of serious floods and prolonged periods of drought, local interests have made a considerable number of improvements on the Trinity River Basin in the interest of flood control and water conservation. These improvements, located for the most part in the upper watershed, consist of levees, channel improvements and reservoirs. The bottom lands along the Trinity River are of great fertility but could not be successfully cultivated in their natural state due to the frequent flooding. Most of the levees constructed by the local people were for the purpose of reclaiming these fertile lands for agricultural purposes; however, levees also were built to protect urban areas of Fort Worth and Dallas. Some of the levees were constructed by private individuals or groups, but the larger ones were constructed by levee improvement districts organized under State law. The first levee improvement district in the Trinity River Basin was organized in 1909 for the protection of the lowlands adjacent to the city of Forth Worth, where considerable damage had been experienced during the flood of 1908. To date, fifty-six authorized levee improvement districts have been organized in the basin. In addition to the State-authorized districts, there are about fifty private levees along the main stream and its tributaries. Of the fifty-six State-authorized districts in the basin, four were created for the protection of the lowlands adjacent to Fort Worth and Dallas. In addition to the levees, local interests have constructed reservoirs in the upper Trinity River Basin. Only two of the reservoirs are of significance with respect to flood control.

With the passage of the Flood Control Act of 1936, Congress decided that it was proper for the Federal Government to participate in flood control activities on a national scale. By this time, it had long been evident to the people of the Trinity River Valley that their flood control efforts were inadequate. Practically all of the agricultural levees had been overtopped and damaged from time to time. The Fort Worth levees had been overtopped in the 1922 flood. Realizing the need for additional flood control measures planned on a watershed basis, the local people petitioned the Congress for assistance under the policy embodied in the 1936 Flood Control Act. As a result, the Corps of Engineers was directed by Congress to make a comprehensive study of the Trinity River Basin in the interest of flood control and allied purposes.

Accordingly, a comprehensive report on the Trinity River and its tributaries was prepared. In 1941, the Chief of Engineers transmitted this report to the Congress for consideration. The Chief of Engineers recommended, for flood control purposes, primarily, the construction of dams on the Clear Fork, Denton Creek, Elm Fork and East Fork; he also recommended certain modifications to the floodway projects at Forth Worth and Dallas, which projects had already been constructed at local expense.

As a result of the recommendations contained in this report, the Congress, in the River and Harbor Act of 1945, authorized the construction of four reservoirs on the upper Trinity watershed, the modification of the floodways at Fort Worth and Dallas, and a navigation channel in the lower reaches of the river. The four Federal reservoir projects are the Benbrook Reservoir on Clear Fork, the Grapevine Reservoir on Denton Creek, the Garza-Little Elm Reservoir on Elm Fork, and the Lavon Reservoir on East Fork. The River and Harbor Act of 1946 authorized modification of the Lavon Reservoir

TABLE 1

MAJOR RESERVOIRS
UPPER TRINITY RIVER WATERSHED

Reservoir	Stream	Drainage Area Sq. Mi.	Storage (Acre-Feet) Controlled Flood Storage	Conservation	Sedimentation
Non-Federal Reservoirs					
Bridgeport	West Fork	1,114	524,000	229,000	40,300
Eagle Mountain	West Fork	860[a]	458,000	121,500	60,400
Lake Worth	West Fork	95[b]	---	26,480	7,220
Mountain Creek	Mountain Cr.	289	---	8,020	16,380
White Rock	White Rock Cr.	103	---	17,500	---
Sub-total		2,461	982,000	402,500	124,300
Federal Reservoir Projects					
Benbrook	Clear Fork	433	170,350	72,500	15,750
Grapevine	Denton Cr.	694	238,250	161,250	36,000
Garza-Little Elm[c]	Elm Fork	1,658	526,700	436,000	53,500
Lavon	East Fork	777	275,600	100,000	47,800
Sub-total		3,562	1,210,900	769,750	153,050
Grand Total		6,023	2,192,900	1,172,250	277,350

[a] Between Bridgeport and Eagle Mountain Dams
[b] Between Eagle Mountain and Lake Worth Dams
[c] Encompasses existing Lake Dallas

project to include conservation storage and the River and Harbor Act of 1950 authorized modification of the Dallas Floodway project to provide for the installation of interior drainage facilities.

The storage capacities of the major non-Federal and Federal reservoir projects on the upper Trinity watershed are given in table 1.

The Bridgeport and Eagle Mountain Reservoirs were built by the Tarrant County Water Control and Improvement District No. 1 on the West Fork to provide a municipal water supply and flood control for Fort Worth. Bridgeport Reservoir was placed in operation in 1932 and Eagle Mountain Reservoir was placed in operation in 1934. Lake Bridgeport is located about 43 miles above Fort Worth, and Eagle Mountain Lake is about 11 miles above Fort Worth. Releases from Lake Bridgeport are controlled by three 48-inch valves, one 30-inch valve, and a 60-foot ogee spillway, consisting of three 20-foot bays, two of which are gated and one uncontrolled. Flow from Eagle Mountain Lake is controlled by four 48-inch valves and a 100-foot ogee spillway consisting of four 25-foot bays, three of which are gated and one uncontrolled. Lake Worth, located on the West Fork about 5 miles above Fort Worth, was built by the city of Fort Worth in 1913 to provide a water supply for municipal purposes. Flow from Lake Worth is regulated by a 700-foot uncontrolled ogee spillway. The total cost of constructing Bridgeport, Eagle Mountain, and Lake Worth Dams was $7,533,000.

The Mountain Creek Reservoir was constructed by a private company for the purpose of impounding water for cooling and condensing in connection with the steam generation of electric power.

White Rock Reservoir was constructed in 1911 by the city of Dallas for a municipal water supply. The reservoir is now maintained for park recreational purposes and as a reserve supply for emergencies.

The four Federal reservoir projects; namely, Benbrook, Grapevine, Garza-Little Elm and Lavon Reservoirs have been completed and placed in operation. The Fort Worth Floodway project will be completed this year and the Dallas Floodway project is scheduled for completion in 1958.

The Benbrook project is located about 10 miles southwest of Fort Worth, on the Clear Fork of the Trinity River. The dam is an earthfill structure 9,130 feet in length including an uncontrolled concrete spillway 500 feet in length. The dam has a maximum height of 130 feet. Regulated releases from the reservoir are made through a 13-foot diameter, gate-controlled, flood control conduit and two 30-inch low-flow outlets. Construction of the project was started in 1947 and the project was placed in operation in 1952. The Benbrook project is designed to prevent floods similar to the disastrous flood of May, 1949, when 11 people lost their lives, vital business and residential areas of the city of Fort Worth were inundated, and monetary losses were estimated at $11,000,000. By preventing this flood alone, the Benbrook project would have paid for itself.

The Grapevine project is located on Denton Creek, about 20 miles northwest of Dallas. The dam is an earthfill structure 12,850 feet in length, including an uncontrolled concrete spillway 500 feet in length, located in the left abutment. The dam has a maximum height of 137 feet. Regulated releases from the reservoir are made through a 13-foot diameter, gate-controlled, flood control conduit and two 30-inch low-flow outlets. Construction of the project was started in 1948 and the project was placed in operation in 1952. Water conservation storage space provided in the Grapevine project has been acquired by local interests for municipal water supply purposes as

follows: 85,000 acre-feet by the city of Dallas; 50,000 acre-feet by the cities of Highland Park and University Park; and 1,250 acre-feet by the town of Grapevine.

The Garza-Little Elm project is located on the Elm Fork of the Trinity River between Dallas and Denton near the town of Lewisville and the reservoir encompasses existing Lake Dallas. The dam is an earthfill structure 32,888 feet in length, including an uncontrolled concrete spillway 560 feet in length. The dam has a maximum height of 125 feet. Regulated releases from the reservoir are made through a 16-foot diameter, gate-controlled, flood control conduit and two 60-inch low-flow outlets. Construction of the project was started in 1948 and the project was placed in operation in 1954. Water conservation storage space provided in the Garza-Little Elm project, amounting to 436,000 acre-feet, has been acquired by the cities of Dallas and Denton. The city of Dallas has a total storage space of 415,000 acre-feet in the reservoir consisting of 105,000 acre-feet of conservation storage in the new project in return for storage in Lake Dallas and 310,000 acre-feet of additional conservation storage space to meet the city's needs. The remaining 21,000 acre-feet of conservation storage space has been acquired by the city of Denton for municipal water supply purposes.

The Lavon project is located on the East Fork of the Trinity River about 56 miles above its confluence with the Trinity River and about 22 miles northeast of Dallas. The dam is an earthfill structure 9,499 feet in length, including a gate-controlled concrete spillway located in the right abutment. The dam has a maximum height of 69 feet. The gate-controlled concrete spillway contains 12 tainter gates 40 feet wide by 28 feet high and five 36-inch diameter low-flow outlets. Regulated releases from the reservoir are made through the spillway gates and low-flow outlets. Construction of the project was started in 1948 and the project was placed in operation in 1953. Water conservation space provided in the Lavon project, amounting to 100,000 acre-feet, has been acquired by the North Texas Municipal Water District, an agency created by the State of Texas for the purpose of providing water for the domestic and municipal needs of communities in the North Texas area.

The Fort Worth Floodway project, which provides for the improvement of existing levees and floodways, is located in the city of Fort Worth along the West Fork and Clear Fork of the Trinity River. The original levee system in Fort Worth was constructed by local interests after the flood of 1908 at an estimated cost of $335,000. The Federal project, which was begun in 1950, and will be completed this year provides for raising and strengthening the present levees with material excavated from the channel and floodway, clearing the floodway of timber and debris, removing obstructions and enlarging bridge openings by excavation in order to provide a safe capacity of 95,000 second-feet in the West Fork downstream from the mouth of the Clear Fork, 50,000 second-feet in the West Fork above the Clear Fork, and 75,000 second-feet in the Clear Fork from its mouth to Lancaster Street Bridge. The principal project features are: improvement of 52,500 linear feet of channel; strengthening of 50,000 feet of existing levees and construction of 11,600 linear feet of new levee; improvement of floodway and channel by clearing and removal of obstructions; reconstruction of 3 highway bridges, and alteration of 3 highway bridges, 6 railroad bridges and public utilities; and, removal of an existing channel dam and construction of a channel dam with improved hydraulic efficiency. The Fort Worth Floodway project, together with the Benbrook project, will provide a high degree of flood protection for 2,080

acres of Fort Worth's highly developed industrial and residential property located in the flood plains of the West Fork and Clear Fork of the Trinity River.

The Dallas Floodway project, which provides for the improvement of existing levees and floodway and installation of interior drainage facilities, is located in the city of Dallas on the Elm Fork, West Fork, and main stem of the Trinity River. The existing levee and floodway improvements at Dallas were constructed by local interests during the period 1928 to 1932. The cost of this original work, including rights-of-way, bridges, utilities, etc., has been estimated at $20,000,000. The Federal project, which was begun in 1953, and is scheduled for completion in 1958, provides for the strengthening of approximately 23 miles of existing levees and clearing the floodway channel to provide a safe capacity of 226,000 second-feet and improvement of interior drainage facilities. In connection with this program, construction of an addition of an addition to the existing pumping plant "A" near Houston Street and a new pumping plant near the foot of Pavaho Street have been completed. The plan further calls for construction of two pressure sewers, one in the Turtle Creek area and one in the Lake Cliff area; the Coombs Creek Diversion; and construction of a pumping plant near Hampton Road. The Dallas Floodway project, together with the Grapevine and Garza-Little Elm projects, will provide a high degree of protection for approximately 10,500 acres of highly developed industrial and residential property located in the flood plain within the city of Dallas.

The Federal flood control project was planned on a watershed basis and in cooperation with the local interests. Consideration of water supply was of great importance in planning the four Federal reservoir projects as they are located in an area of rapidly increasing water usage and of limited water resources. From the standpoint of flood control, it was necessary to consider two types or degrees of protection. The highly developed urban areas of Fort Worth and Dallas clearly justify a higher degree of flood protection than does the agricultural lands.

Flow of the Trinity River at Dallas has been measured since 1903. Flow measurements on the principal tributaries are available since 1923. The flow of the Trinity River at Dallas in the period of record has varied from zero to 184,000 c.f.s. The maximum monthly flow was 1,610,000 acre-feet while, in the record drought, the total flow for 58 consecutive months was only 528,928 acre-feet. These extremes of flow are typical of Texas streams and illustrate the need for control by storage reservoirs.

In establishing the capacities of the Federal reservoirs for flood control, a thorough study was made of the floods of record on the upper Trinity River, as well as the flood potential as reflected by rainfall and runoff records of the region. Based on these studies, sufficient controlled flood storage was provided in each reservoir to control the maximum flood of record to an outflow that would not exceed the capacities of the stream channels. This storage, together with the reservoirs and levees constructed by local interests, provides good protection for agricultural lands from the reservoirs downstream to the mouth of Richland Creek. The larger part of the improved farm lands of the basin are in this area.

Additional flood protection for the urban areas of Fort Worth and Dallas was provided in the design of the Benbrook, Grapevine and Garza-Little Elm Reservoirs so that with the improved floodways protection would be afforded against the maximum probable flood. This additional protection in the

Grapevine and Garza-Little Elm Reservoir was accomplished by limiting the width of the uncontrolled spillways so that the combined outflow could not exceed the capacity of the Dallas Floodway. In the Benbrook Reservoir, additional flood storage was provided specifically for the protection of Fort Worth. Control of this block of storage is by means of an uncontrolled 100-foot wide notch with crest 14 feet below the crest of the spillway. The width of the notch was established so that outflow from it, when combined with the maximum probable inflow below the reservoir, would not exceed the capacity of the Clear Fork branch of the Fort Worth Floodway. It is considered of primary importance that the operation of the three reservoirs for the protection of Fort Worth and Dallas is entirely uncontrolled and free of the possibility of human error.

The capacities provided in the reservoirs for water supply were established generally in cooperation with the local interests and, in most cases, are the storages available from full development of the reservoir sites after allocation of storages needed for flood control. In addition, sufficient sediment storage was provided to contain the estimated accumulation of sediment deposits for a period of 50 years.

The foregoing criteria resulted in an allocation in the four Federal reservoirs of 1,210,900 acre-feet of controlled flood storage, 769,750 acre-feet of conservation storage, and 153,050 acre-feet for the accumulation of sediment. A large portion of the conservation space is designated specifically for the use of cities and water districts in meeting domestic and municipal needs in the upper Trinity watershed. These local agencies have assumed that portion of the reservoir cost allocated to the conservation storage.

The total cost of the four reservoir and the two floodway projects is currently estimated at $75,100,000. Of this amount $62,300,000 will be expended by the Federal Government and $12,800,000 will be expended by local interests in connection with the conservation aspects of the reservoir projects and for carrying out the part of the work they have assumed in connection with the two floodway projects.

The flood plain of the Trinity River and its tributaries, on which flood protection will be provided in varying degrees by the Trinity River flood control project, is composed of about 762,000 acres. Of the total of 762,000 acres, 244,300 acres are improved farm lands, 497,800 acres are lands either wooded or devoted to grazing, and the remaining 19,900 acres comprise the urban areas of Fort Worth and Dallas.

Operation of the Benbrook, Grapevine, Garza-Little Elm, and Lavon Reservoirs, in coordination with the existing non-Federal reservoirs on the West Fork and in combination with the Fort Worth and Dallas floodway projects, will afford a high degree of flood protection for the leveed portions of the cities of Fort Worth and Dallas and a reasonable degree of supplementary flood protection for the rural areas in the flood plain between the reservoirs and the mouth of Richland Creek, where extensive levee improvements have been made by local interests. Below the mouth of Richland Creek a certain amount of flood protection will be provided from a decrease in the stage and frequency of flooding.

From the standpoint of economic justification, the Federal reservoirs and floodways are outstanding. Just one overflow of the urban areas of Fort Worth and Dallas would result in flood losses far in excess of the total cost of the projects. The benefits to rural lands is great, both in flood damages

prevented and in enhancement of land values through the higher type of use made possible.

The storage space allocated in the Federal reservoirs to water supply purposes creates a dependable supply during the worse drought anticipated of 217 million gallons per day. Present indications are that this supply will be fully utilized within the next ten years. At a rate which is reasonable in the foreseeable future for raw water in this part of Texas for municipal use, the value of the water supplies created is more than sufficient to justify the entire cost of the reservoirs including the flood control pools.

Congress has also authorized the Corps of Engineers to make a detailed review of the entire Trinity River Basin. In this connection, investigations and studies are being made to the extent possible consistent with the amount of funds being made available for this purpose. As a result of these studies and investigations, the Navarro Mills Reservoir project on Richland Creek in the Trinity River Basin was authorized by the Flood Control Act of 1954. Funds to initiate detailed planning for this project were appropriated by Congress during the past year. At the present time, studies are being made on the Richland and Chambers Creeks watershed to determine if additional improvements for flood control are warranted and a study is also underway in connection with the proposed Lake Liberty Reservoir located on the lower reaches of the Trinity River a short distance upstream from Liberty, Texas.

It appears that the most important single requirement for the continued expansion of the economy of the Trinity River Basin is the control and conservation of its water resources. The area has progressed greatly already and it probably will continue to progress in proportion to the use that is made of its water resources.

Paper 935 WW 2

JOURNAL
WATERWAYS AND HARBORS DIVISION
Proceedings of the American Society of Civil Engineers

BRIDGE CLEARANCES: POLICIES AND PRACTICE

Eugene W. Weber,[1] M. ASCE
(Proc. Paper 935)

FOREWORD

This paper is one of a group of five concerned with certain phases of the physical characteristics of bridges crossing waterways as they affect water and land traffic. All were presented at the Annual Convention of the ASCE in New York on October 24, 1955.

The symposium arose from a concurrent growing awareness on the part of engineers concerned with waterway, highway, and railroad traffic of the need for rationalizing any extreme views as to appropriate navigation clearances. In the first of these papers "Bridge Clearances: Policies and Practice" (Proc. Paper 935) Eugene W. Weber traces the evolution of the bridge-clearance problem and discusses existing law and practice toward realization of reasonable clearance requirements from the standpoint of all affected forms of transport. "Bridge Clearances: The Interest of the Bureau of Public Roads" (Proc. Paper 936) Walter Kurylo presents the view that navigation clearances of bridges should be based on the least overall cost to the public and studies should be made to determine the most economic solution. William E. Cleary in "Bridge Clearances: Need for Realistic Approach" (Proc. Paper 937) states the position of the waterway operators as opposed to "standard clearances" and emphasizes the need for a cooperative and reasonable approach to the problem. The paper "Bridge Clearances: The Operator's View" (Proc. Paper 938) by N. L. Caruthers, emphasizes the importance of navigational clearances to rational economic development and water transportation, and stresses the need of cooperative and realistic approach to the problem. The last paper by E. E. Dittbrenner "Bridge Clearances: Problems in Northeastern United States" (Proc. Paper 939) describes the industries, resources, and transportation and their proper coordination and integration.

With an impending national highway program of unprecedented magnitudes these papers have timely significance in their effect upon adequacy of clearances and cost of bridge construction.

Note: Discussion open until September 1, 1956. Paper 935 is part of the copyrighted Journal of the Waterways and Harbors Division of the American Society of Civil Engineers, Vol. 82, No. WW 2, April 1956.

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SYNOPSIS

The development of transportation facilities has been accompanied by problems of necessary intersections of the various modes of transport. In the first half of the nineteenth century there was little conflict between water and land transport and thus relatively few bridge clearance problems. With the development of railroads in the latter half of the century, navigational clearance at bridges became important and Federal legislation was adopted to deal with it. During the past 50 years highway transport, the resurgence of waterways traffic and the continued development of railroads have resulted in radical changes in the nature and intent of the bridge clearance problem. The history of the problem and the steps necessary to solve it are developed by the author.

The development of the nation's transportation facilities by waterway, railroad and highway over the years has been accompanied by constantly changing problems with respect to the necessary intersections of the various modes of transport. As speeds increased, for example, we had to face the problem of grade crossings of highways and railroads and we are now involved in developing super highways to separate high-speed traffic.

For consideration of the specific problem before us today—that of clearances at bridges over navigable waters—it is convenient to consider the evolution of the problem in the three half-century periods from 1800 to date.

In the first half of the nineteenth century our principal means of long distance transport was by water and there were relatively few bridge clearance problems.

The last half of the nineteenth century saw the development of the railroads as the principal means of long distance transport inland. During this period the problem of navigational clearances at bridges became serious and Federal legislation was adopted to deal with it.

During the last 50 years we have developed a great highway system and have seen a resurgence of inland waterway traffic as well as continued rail development to meet the tremendous growth in our transportation requirements. It is during the latter part of this most recent 50 years that the nature and extent of the bridge clearance problem has changed most radically.

In tracing the evolution of the bridge clearance problem, one of the earliest and most interesting developments is a case which arose over a hundred years ago concerning the Wheeling Bridge across the Ohio River. The State of Pennsylvania contended that the bridge was an obstruction to navigation. The Supreme Court analyzed the pertinent considerations involved, including the size and type of vessels, the feasibility of altering the vessels, the delays to navigation attributable to the bridge, the costs of bridge alterations to accommodate navigation and the relative importance of the land and water traffic. The Court decided that the bridge was obstructive to navigation but the Congress by an Act of 31 August, 1852, legalized the bridge and thus forced water traffic to conform to the limitations imposed by the clearances which it then had. This case is noteworthy for at least two reasons. First, it is an early example of an attempt to determine, by "economic analysis," a proper balance between the adverse impact of a bridge upon water traffic and the adverse impact of navigation requirements on bridge costs. Second, it was an exercise

by Congress of its prerogative to regulate commerce in a manner which favored land transport at the expense of water transport.

Until 1890, the regulation of construction of bridges over waterways was left to the States except for separate actions by Congress from time to time authorizing specific bridges and, in some cases, prescribing the navigation clearances. Meanwhile, the inland waterways were being extensively improved by the Federal government to meet the growing needs for water transportation and, at the same time, as we entered the great era of railroad construction, more and more bridges were being built over navigable waters without effective control of their clearances for the waterway traffic. Many difficult and undesirable situations which exist today at land transport crossings over navigable waterways are traceable to actions taken during this period of ineffective control of bridge construction. After an initial attempt at general bridge legislation in 1890, Congress finally passed the comprehensive Act of March 3, 1899, which was the foundation of the Federal legislation applicable today to bridges over navigable waters.

Under the Act of 1899 and subsequent amendments and related legislation, the determination of the suitability of plans and of the clearances to be provided for navigation at bridges over navigable waters of the U. S. has been a responsibility of the Corps of Engineers.

It is only in the last fifty years, therefore, that procedures have been available for effective determination of the proper requirements for navigational clearances at bridges. In carrying out its responsibility, the Corps of Engineers has followed the practice of obtaining the views of interested parties on the proposed construction of bridges over navigable waters by direct inquiry, public hearings and other appropriate procedures. At the turn of the century, railroad and waterway operators were often the only parties expressing an interest. In any event, all pertinent factors on each proposed bridge were analyzed to determine the reasonable requirements for navigation clearances.

As the volume of traffic at railroad and highway crossings over waterways increased, it became necessary to improve and refine the methods for analysis of bridge clearances in order to insure accurate and proper determinations.

Prior to and during the 1930's, standard bridge clearances had been established for most of the major seaport areas and inland waterways, including the Mississippi, the Ohio, the Illinois, the Missouri, and the Atlantic and Gulf Intracoastal Waterways. Although such standard clearances facilitated planning by all transportation agencies, it is considered essential that they be kept constantly under review and that each proposed new bridge be analyzed on its own merits to determine the clearance provisions which will result in the least total cost to the public for transportation by the most logical combination of water and land facilities.

It is necessary to look back only a few years to note the drastic changes which can take place in the inter-relation of our transport media. As the railroads were developed and the proportion of our dependence on waterways decreased, many railroad bridges were built with clearances which were thought reasonable for the navigation requirements foreseeable at that time. Within the economic life span of many such bridges, however, the need for waterway facilities for bulk inland water transport has made it necessary to undertake expensive alterations to eliminate uneconomic interference with waterway traffic. Since passage of the Truman-Hobbs Act in 1940, the Federal

government has embarked on a program of alteration of some 50 obstructive bridges under the provisions of that Act and under special projects consistent with the Act's provisions at a total estimated Federal cost of more than $130 million. In addition non-Federal costs in connection with this program will bring the total expenditure to about $200 million.

The fact that bridge clearance practices to date have resulted in inadequate navigation clearances requiring such vast expenditures to correct has generally received less recognition than has been accorded to those examples where the clearances for navigation have proven, with changing times, to be no longer justified. Perhaps this is due to the fact that many of us as individual motorists have acquired personal knowledge of the impact of waterway requirements on bridges but relatively few have occasion to observe or note the impact of obstructive bridges on navigation. In any event it has become evident that our efforts to improve our determinations of navigational clearance requirements at bridges should be intensified because the tremendously increased volume of both land and water traffic has added to the significance of the possible adverse effects on one form of transport or the other when the clearances are not satisfactory.

In the light of the drastic changes which have taken place in transportation facilities in the last 50 years, it is not surprising that we have today many bridges over navigable waters with clearances that are inappropriate in the light of present day traffic requirements, both by land and water. In analyzing a bridge clearance problem 50 years ago, how many of us would have accurately envisioned the type of highway transport we have today? Even in more recent years when modern types of automotive transport were well developed few would have predicted accurately the volume of such traffic that is now developing. Similarly, during the development of our great rail network and the relative decline in waterway traffic, few would have envisioned the increasingly important role that inland waterways are now playing in transportation of bulk commodities. Of the existing draw bridges on which operation of the draw span is no longer required because of changed conditions about half were built 50 years or more ago and were required to have draw spans on the basis of conditions foreseen at that time. Also, practically half of the bridges which are currently being found obstructive to navigation and which were permitted to have inadequate navigation clearances when they were built, are 50 years old or more. From 85% to 90% of all bridges now having improper clearances from the standpoint of either land transport or waterway transport requirements were built more than 25 years ago. It is clear from the information available that much, if not most, of our bridge clearance problem today stems from our inherent inability to forecast future developments accurately rather than from any basic inadequacy of the laws and practices that have been applicable since 1900.

One of the most important recent steps toward improvement of bridge clearance determinations had its origin in the Federal Inter-Agency benefit-cost studies which culminated in a report in May 1950, entitled, "Proposed Practices for Economic Analysis of River Basin Projects." This report, which is often referred to as the "Green Book," has formed the foundation for improved practices for economic analysis in many agencies engaged in the development of water and related land use projects. The Corps of Engineers, as one of the agencies participating in development of the "Green Book" principles, has adapted the applicable portions of those principles to the problem of determining bridge clearance requirements in two ways.

First, in preparing reports on prospective navigation improvements, arrangements are being made to insure that the analysis will include a complete accounting of the impact of such improvements on land transport. The Corps of Engineers' procedures for analyzing prospective navigation improvements have for many years included provision for obtaining views and data from all affected interests. However, until recently when the problems of our expanding highway network and its waterway crossings became more and more acute, the Corps was able to obtain relatively little definite information on highway requirements for use in analyzing waterway projects. It is expected that recent improvements in the practices of all agencies concerned with this aspect of the problem will result in better correlation of water and land transport needs and thus, in the long run, result in more adequate bridge clearance criteria.

The second way in which improved economic analysis procedures will help in the bridge clearance problem is through improvement of the analysis of individual bridge proposals. In a recent case involving a bridge on Highway No. 65 across the Minnesota River near Minneapolis, Minn., the Corps analyzed the bridge costs and adverse effects on land transport over a range of vertical clearance requirements and analyzed the economic impact of the same range of clearances on expected water traffic. The point at which there was the least total adverse economic effect on transportation by both land and water was recommended as the proper vertical clearance requirement for the bridge. It is expected that this procedure will be effective in determining reasonable and proper bridge clearances providing satisfactory data on prospective land and water traffic can be obtained for use in the analysis.

Because of the pronounced changes in transport facilities in recent years, the Bureau of Public Roads of the Department of Commerce has become increasingly concerned with the bridge clearance problem. Largely as a result of the initiative and concern of the Bureau of Public Roads, the Department of Commerce, with appropriate assistance and cooperation of other agencies concerned with transportation planning and development, prepared a report entitled, "Navigational Clearance Requirements for Highway and Railroad Bridges" in February, 1955. The report is a comprehensive analysis of the land transport aspects of the bridge clearance problem. As a result of this study and report there is now a better realization of the relative interests and responsibilities of the various agencies, Federal and non-Federal, that are concerned with the problem of bridge clearances over navigable waters. Further studies, particularly of the water transport aspects of the problem, are also needed.

In summary, the question of the proper amount of clearance to be provided at bridges over navigable waters has become acute in recent years primarily because of changes in both land and water transport facilities and the tremendous increase in the volume of traffic. Part of the problem stems from practices prior to the turn of the century before adoption of adequate procedures for determining the proper clearances. These are no obstacles in existing law and practice to realization of the goal of reasonable clearance requirements from the standpoint of all affected forms of transport. Efforts have been intensified in very recent years towards improving the procedures for determining future bridge clearances and for easing existing problems brought about by changing conditions. The continued cooperation of all agencies, Federal and non-Federal, along lines that have been developed recently, is needed to insure satisfactory progress in solving the bridge clearance problem.

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BRIDGE CLEARANCES: THE INTEREST OF THE BUREAU OF PUBLIC ROADS

Walter Kurylo*
(Proc. Paper 936)

FOREWORD

This paper is one of a group of five concerned with certain phases of the physical characteristics of bridges crossing waterways as they affect water and land traffic. All were presented at the Annual Convention of the ASCE in New York on October 24, 1955.

The symposium arose from a concurrent growing awareness on the part of engineers concerned with waterway, highway, and railroad traffic of the need for rationalizing any extreme views as to appropriate navigation clearances. In the first of these papers "Bridge Clearances: Policies and Practice" (Proc. Paper 935) Eugene W. Weber traces the evolution of the bridge-clearance problem and discusses existing law and practice toward realization of reasonable clearance requirements from the standpoint of all affected forms of transport. "Bridge Clearances: The Interest of the Bureau of Public Roads" (Proc. Paper 936) Walter Kurylo presents the view that navigation clearances of bridges should be based on the least overall cost to the public and studies should be made to determine the most economic solution. William E. Cleary in "Bridge Clearances: Need for Realistic Approach" (Proc. Paper 937) states the position of the waterway operators as opposed to "standard clearances" and emphasizes the need for a cooperative and reasonable approach to the problem. The paper "Bridge Clearances: The Operator's View" (Proc. Paper 938) by N. L. Caruthers, emphasizes the importance of navigational clearances to rational economic development and water transportation, and stresses the need of cooperative and realistic approach to the problem. The last paper by E. E. Dittbrenner "Bridge Clearances: Problems in Northeastern United States" (Proc. Paper 939) describes the industries, resources, and transportation and their proper coordination and integration.

With an impending national highway program of unprecedented magnitudes these papers have timely significance in their effect upon adequacy of clearances and cost of bridge construction.

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INTRODUCTION

About eight months ago, the Department of Commerce released the first comprehensive report on the navigational clearance problem ever made in American transportation history.(1) The study leading toward that report was based upon four fundamental premises. Those premises were cemented into the Commerce publication, which has isolated this problem.

The first premise was that all transportation costs are ultimately borne by the general public in the cost of goods consumed, in prices paid for services received, and in taxes.

The second was that our expanding economy is dependent for surface transportation not on our waterways alone, nor our railways alone, not even our highways alone; but that all three forms of movement are essential to a coordinated surface transportation system. Since pipelines are assuming increasing importance in economical movement of certain types of commodities, they also should be included in this thought.

The third premise was that sufficient factual material should be collected and evaluated to form the basis for sound conclusions and recommendations.

The fourth was that every Federal agency having an interest in this problem, or whose activities might in any way be affected by the results of the study, should be given a real opportunity to cooperate in the undertaking and to have its views included in the report.

The study involved the cooperation of a number of Federal agencies, and the report included information received from over 40 State highway departments and some 60 railroads. It contains incontrovertible facts concerning bridge operating conditions and realistic estimates of the navigational increment to the cost of bridges.(2)

Evidence collected in the study shows that—as between railroads and highways—for some years the highway transportation economy has been bearing a heavy burden of bridge costs due to navigational needs. Existing and prospective future conditions strongly suggest that highway transportation will continue to bear this burden for some time to come. This knowledge highlights the basis for Public Roads interest in bridge clearances.

This problem has many intricate complexities. Understandably, there are diverse and conflicting viewpoints as to its effective treatment. Certain waterway groups probably prefer to leave things as they are. Certain overland transportation groups may hope for complete relief from costs arising from navigational requirements. In Public Roads we believe that the answer should reflect the overall public interest.

In striving for effective treatment of the problem the Bureau of Public Roads will abide by the sound premises that are basic to the Commerce report. Also, we are committed to support the Department of Commerce recommendations for remedial action.(3)

A Change in Concept Concerning Bridge Clearances

The Commerce report and other recent developments with respect to bridge clearances clearly show that treatment of this problem is in transition. The change is from a concept that has expressly required the interests of navigation to be protected in bridge clearance decisions, oftentimes without regard to overall costs or transportation economics,(4) to one that expressly requires protection of the public interest with particular emphasis on overall

costs and transportation economics. Under this new concept the protection of the public interest also takes into account the needs of federally-owned defense watercraft and other special needs of craft navigating deepwater channels.

The Corps of Engineers formally recognized this concept almost a year ago. Following discussions with the Department of Commerce relating to inclusion of Corps of Engineers views in the Commerce report, the Corps issued a statement of policy, practice and procedure governing the construction of bridges over navigable waters. That policy calls for an economic analysis of comparative costs and benefits in bridge clearance decisions.(5)

Other recent actions confirming the emergence of this concept are the decision of the Chief of Engineers and the Secretary of the Army on the navigational clearances for the Lyndale Avenue Bridge across the Minnesota River in Minnesota;(6) an administrative instruction recently issued by the Bureau of Public Roads;(7) a statement in the Hoover Commission report on water resources and power;(8) and a recommendation made by that Commission's task force which studied this problem.(9)

A New Era of National Transportation Policy

In this transitional period, all surface transportation interests stand at the threshold of a new era of national transportation policy concerning navigational clearances for bridges.(10) It is fitting, therefore, for all of us to review in perspective. From such a review there can be charted a course of action that will enable all of us to cross the threshold with integrity, with mutual respect, and with an objective appraisal of the responsibilities that lie ahead.

It is generally agreed that the data collected for the Commerce report were adequate for the purpose of policy revision. We in Public Roads believe that the information was more than enough for that purpose. Yet, we fully realize, as do many others concerned with this problem, that the Commerce report merely defrosted a small section of opaque glass as a means of obtaining a fresh look at the problem. Since corrective action is indicated, the entire pane of glass should be defrosted. The defrosting process should enable all segments of the public to examine this problem with equal visibility from both sides of the window. Additional scientifically prepared information, nationwide in character, is needed to enhance the validity of the proposed standard navigational clearances for bridges. Such information also is needed for decisions concerning the navigational clearances to be required for individual structures.(11)

The needed data unquestionably should be prepared in conformity with the premise that the general public is entitled to transportation services at the lowest possible overall cost. This premise is sound because it does not favor any specific form of transportation. It also is sound because it recognizes the coordinate existence of all forms of transportation and it does take into account the overall public interest.

Action is Required

With these thoughts in mind, all of us will agree that much needs to be done in the immediate future. We in the Bureau of Public Roads would like to suggest certain areas in which action is needed with special reference to waterways having an existing or authorized channel depth of not more than 12 feet—

this means the inland streams and the intracoastal waterways. Because my comments may not be entirely applicable to the question of bridge clearances across channels having an existing or authorized depth of more than 12 feet, that aspect of the problem is not being covered in this paper. For brevity purposes, the text of this paper, then, makes no further reference to this limitation of the discussion.

In addition to the information now being obtained by the Corps of Engineers and published in its Transportation Series, there is a real need for identifying more specifically the nature and purpose of all fixed projections, and the cost of feasible alterations, on watercraft which extend 20 feet or more above water when the craft are light.(12)

This suggestion is not intended to imply that the vertical clearance for future bridges across the inland streams and intracoastal waterways should be fixed at 20 feet above high water without regard to additional facts. As a general observation, it does mean that where adequate navigation exists, except possibly in rare instances, the vertical navigational clearance for any fixed bridge across the waterway would be not less than 20 feet above water. Subject to this general observation, the actual vertical navigational clearance would be based upon an economic analysis of all relevant facts. Surely, in the face of information which indicates that more than 80 percent of all watercraft operating on the inland streams and intracoastal waterways have fixed projections of less than 20 feet, any objective observer will agree that there is no need for detailed study of any of the craft in this category. The same observer also would agree that the remaining craft—those having projections of 20 feet or more—are within the area of the problem which requires detailed analysis.

There appears to be no reason why all affected public and private waterway transportation interests would not be willing to cooperate with the Federal Government by providing the additional facts.

This study of watercraft projections also should identify the extent to which federally-owned watercraft engaged in waterway construction or maintenance, or in providing aids to navigation, may be influencing bridge clearances and bridge costs. The imposition upon governmental agencies engaged in constructing publicly financed highway bridges of added bridge costs for accommodation of government-owned craft performing services relating to waterway transportation, without having those costs offset by equal or greater public benefits, obviously is not sound public policy.(13)

The study also should reveal whether rules prescribing the height of lights on craft need be modified. The thought that the public may be required to pay added millions for highway bridge clearances to accommodate navigational lights on relatively few watercraft, without a realistic evaluation of alternatives, is sufficient to arouse the curiosity of any taxpayer.(14)

Since certain watercraft operators have been contending that lowering of masts and similar projections would unduly interfere with the operation of radar and other communications media, communications experts need to explore ways and means of overcoming the difficulties. The innovations needed here are no different from the improvements made in communications and transportation media in other activities.(15) Here, again, the added cost of the most suitable innovation should be included with other watercraft costs that may be compared with possible reductions in bridge costs resulting from lower bridge clearances.

A special review is needed of existing minimum standard navigational

clearances for bridges. The facts already available in the Commerce report on the Gulf Intracoastal Waterway, which has a minimum vertical clearance of 73 feet for fixed bridges, demonstrate the urgency of this situation.(16)

Information is needed on the necessity of operating and maintaining movable bridges, especially in urban areas, and of requiring movable spans or extraordinary navigational clearances in new or replacement structures. The evidence should reveal the extent to which bridges costs due to navigational needs are now being offset by equal or greater savings in waterway transportation costs. Where such savings are not indicated, corrective action may be required.(17)

Naval architects and marine developmental interests have a real opportunity to include adaptations in watercraft now on the drawing boards or in early construction stages. Features that will enable the craft to navigate under fixed bridges having reasonable navigational clearances can be added at far less cost during construction of the craft than at a later date. Early action of this kind would be a very significant step toward desirable standardization of floating units in this category.(18)

Overland transportation interests, highway and rail, should ascertain more clearly their need for future bridge construction across navigable waterways, based upon traffic conditions expected within the next 20 years. They also should realize that in filing an application for a permit to construct a bridge across a navigable waterway, they may request the Corps of Engineers to establish navigational clearances based on transportation economics. Such requests, of course, are subject to any special needs of federally-owned defense watercraft.

A study is needed to determine the relationship, under Federal and State constitutions, between the riparian rights of a landowner abutting a waterway and the public right of navigation.(19)

Six Possible Solutions are Suggested

Recognizing that action is needed in the foregoing and other areas, there are at least six possible solutions that may result from efforts to arrive at bridge clearances based upon the lowest overall cost to the public. A different solution may apply to different reaches of the same waterway. The suggested solutions are:

First, to obtain bridge clearances based upon this concept may require alteration and reconstruction of existing structures so as to provide greater navigational clearances than are now available. This condition may be found on streams where waterway transportation has increased from little to considerable importance since bridges were built. In such a case, if the cost of the bridge alterations, and the added cost of foreseeable new bridges due to navigational needs, should be less than the expected savings in water transportation obviously greater clearances are economically justified and should be required.

Second, bridge clearances that are based on this concept may require a modification of watercraft projections so the craft can pass under fixed bridges having lower vertical clearances than are now required. In effect, the decision would be based upon a comparison of added bridge costs due to watercraft needs with the cost of adjusting extreme projections on watercraft so the craft could pass under lower fixed bridge clearances than they now require. A similar method of arriving at the lowest overall transportation cost being borne by the public also might be used.(20)

Third, overall public savings might be achieved by shifting an existing waterway terminal downstream from its present location. Such a shift would permit closure or reduced operating conditions on movable span bridges and the construction of new or replacement bridges as fixed structures affording reasonable navigational clearances.(21)

A fourth possible solution is to remove any requirement of navigational clearance for a new bridge to cross a specific reach of waterway and to permit all existing movable bridges on the reach of waterway to be permanently closed. Conditions warranting this solution may be found primarily on the upper reaches of certain navigable waterways, in urban areas where many movable bridges cross the waterway, where a number of new or replacement structures are contemplated, and where a relatively small volume of traffic moves on the waterway. In such cases, if expected bridge costs due solely to navigational needs cannot be offset by equal or greater savings in waterway transportation costs, there obviously will be no justification for navigational clearances in new or replacement bridges.

A fifth possible solution involves the formal declaration of a waterway as nonnavigable, by Act of Congress. A number of such enactments already are in the statute books.(22) During its first session, the 84th Congress this year enacted five laws declaring portions of waterways as nonnavigable. Three of these waterways are in Connecticut,(23) the fourth is in Kenosha, Wisconsin,(24) and the fifth in Boston, Massachusetts.(25) Such enactments automatically eliminate the need for considering navigational clearances. Also, bridges can be constructed without the usual Federal permits.

A sixth possible solution is retention of the status quo. Waterway interests throughout the country can be assured that the Bureau of Public Roads will not advocate reduction in bridge clearances where they are economically justified. As a public agency responsible for promoting the development of one means of transportation, the Bureau is fully aware of the need for other forms of movement. Nevertheless, since we are charged with responsibility for expending public funds, we have a duty—imposed by the Congress and the public—to insure that every dollar we spend is bringing a dollar or more in return. In this regard, the profit motive that actuates private enterprise—which many ASCE members represent—is equally applicable to the conduct of this area of the public business.

Jurisdiction is Discussed

The last point I shall mention is related to the interest of the Bureau of Public Roads in jurisdictional aspects of bridge clearance matters. It would be sheer folly for me to say that Public Roads has no interest in jurisdictional matters. On the other hand, it is most appropriate to spell out our interest as clearly as we can—for the benefit of all concerned.

The Bureau has no interest whatever in obtaining for itself authority to make final decisions in bridge clearance cases. That authority is now vested by law in the Chief of Engineers and the Secretary of the Army.

Our views on the jurisdictional aspects of this problem can be expressed as a continuing desire to maintain mutual respect and integrity in all of our relationships concerning treatment of this problem. Under recently completed arrangements and as a part of normal operations, Public Roads field offices have been instructed to furnish the Corps of Engineers information on expected increases in highway bridge costs due to navigational needs, for inclusion in

pending navigation project reports. These instructions also provide for Public Roads action with respect to pending applications to construct highway bridges on the Federal-aid system. The information being furnished in such cases should contribute toward reasonable decisions concerning navigational clearances for specific structures.

We are especially interested in cooperating with all affected public and private surface transportation agencies and groups in the development of scientifically validated techniques for bridge clearances based upon transportation economics. In conjunction with the development of those techniques, we are prepared to cooperate in the determination of standard navigational clearances for highway bridges.

Our services are available to the State highway departments for economic studies of highway bridge costs relating to the navigational clearance problem in special cases, with a view toward determining the relationship of those costs to waterway transportation benefits, and toward recommending corrective action wherever appropriate. These special studies may well require the cooperation of other surface transportation interests.

APPENDIX

1. The Office of Under Secretary of Commerce for Transportation, U. S. Department of Commerce, Washington, D. C., Navigational Clearance Requirements for Highway and Railroad Bridges, February 1955, 158 pp. For sale by the U. S. Department of Commerce, Room 6225, Commerce Building, Washington 25, D. C., price $1.50 per copy.

2. Ibid, Preface, pp. 30-32, 49-82, 136-141, 144-145. The evidence reveals at least nine significant points concerning conditions and costs in 1950. Those points are:

   a) At least 21 movable span highway bridges in 13 States and two railroad bridges never have been opened for navigation.

   b) No less than 375 movable span highway bridges in 30 States and 179 movable span railroad bridges were opened on an average of once a day or less.

   c) At least 424 movable span highway and railroad bridges were not opened for a year or longer.

   d) Navigational clearances have been required in bridges to accommodate relatively few watercraft, including floating construction equipment and other types of craft having projections not essential for movement of the craft.

   e) The added cost of constructing highway and railroad bridges due solely to navigational needs, as adjusted to 1950 price levels, is conservatively estimated at $754.2 million. This amount is 28 percent of the adjusted construction cost of some 2,200 bridges studied in detail.

   f) The increased cost of maintaining and operating existing bridges due solely for accommodation of watercraft is estimated at $16.9 million annually.

g) The increased cost of vehicular and train operations due to navigation is estimated at $11.3 million annually.

h) On a specific waterway studied in detail—the Altamaha River in Georgia —the added cost of bridges due to navigational needs, when translated into terms of cost per ton-mile of waterway traffic, resulted in an estimate of $0.1375 per ton-mile. On the Kennebunk River in Maine, which carries very little waterway traffic under only one movable span highway bridge, the estimate was $7.24 per ton-mile of waterway traffic.

i) According to conservative estimates from $5 million to $10 million in bridge construction costs, and an additional $1 million in bridge operating costs, can be saved annually without unduly affecting waterway traffic. These savings would be substantially increased under an expanded highway program.

3. Ibid, pp. 2-6. Summarized briefly, those recommendations provide for having bridge clearances due to navigational needs based upon transportation economics, except only as requirements of federally-owned defense watercraft, and craft engaged in foreign commerce and other deepwater transportation are controlling. Where the exception applies, the Federal Government would finance the added cost of bridges due to navigational needs. These basic objectives would be achieved through classification of navigable waterways according to identified uses and through establishment of standard navigational clearances for bridges.

4. On this specific point, in his capacity as Chief of Engineers, United States Army, Lt. Gen. R. A. Wheeler, stated at the 1946 annual convention of the American Society of Civil Engineers:

> "We must meet all reasonable needs of navigation, but we must weigh all conflicting interests, and we must have respect for the cost of things. I would like to think that this entire subject is merely one of economics, with engineering considerations as prime factors. Unfortunately, perhaps, this is not the case. It is a matter of fundamental law that the navigation of a stream is not a matter of economics but of public right." (Underscoring added.)

For Gen. Wheeler's full statement, see "War Department Determines Bridge Clearances Required for Public Navigation, "Civil Engineering," Feb. 1947, Vol. 17, No. 2, p. 71.

5. Office of Chief of Engineers, Department of the Army, Washington 25, D. C., Bridges, Statement of Policy, Practice and Procedure, dated November 3, 1954. (Processed, 5 pages.) In referring to this analysis when speaking before the Mississippi Valley Association in St. Louis, Missouri, February 7, 1955, Brigadier General E. C. Itschner, Assistant Chief of Engineers for Civil Works, said:

> "This analysis is utilized as one part of the study leading to the final decision as to what constitutes an unreasonable obstruction to navigation. Some of the data for the analysis originates with the navigational interests, who must analyze the characteristics of waterway commerce passing the intersection in question and determine the resultant damages or losses if certain restrictive clearances are provided. Conversely, navigational interests must demonstrate the resulting benefits in terms

of dollars to be realized by the provision of clearances proposed by them. The problem resolves itself into one where both land and water transportation interests must fully consider the economic effects of the final decision on the overall economy of the region."

Attention also is invited to an Office of Chief of Engineers, Department of the Army, Memorandum to Division Engineers and others, Subject: Survey Reports; Increased Cost of Overland Transportation, dated June 30, 1955. (Processed, 2 pages.)

6. For the conclusions reached in this case, see Corps of Engineers, St. Paul (Minnesota) District, "Public Notice on the Application of the Minnesota State Highway Department for a Permit to Construct a Bridge Across the Minnesota River on Trunk Highway No. 65," dated 22 June 1955. For the specific details, see the same organization's compilation entitled "Proposed State of Minnesota Highway Bridge Across Minnesota River on Trunk Highway No. 65 (Lyndale Avenue)." The compilation includes communications from the Minnesota Department of Highways, the recommendations of the Corps of Engineers district engineer, an economic analysis of bridge clearances on this waterway, and pertinent tables and charts.

7. U. S. Department of Commerce, Bureau of Public Roads, Policy and Procedure Memorandum 50-4.1, Subject: Highway-Water Resources Developments (Bridge Clearances for Navigation), dated July 11, 1955.

8. Commission on Organization of the Executive Branch of the Government, Water Resources and Power, June 1955, Vol. 1, pp. 83-84. The statement reads:

> "A constant conflict arises between the inland navigators and the highway builders, over higher bridge clearance. Under the present law, the Army Engineers are required to favor navigation.
>
> "A recent report by the Department of Commerce revealed that at least 36 movable-span highway bridges in 17 States never have opened to accommodate navigation, and 122 highway bridges in 25 States have not been opened for navigation for a year or longer. In addition, at least 119 movable-span railroad bridges were not opened for navigation during the year, and at least 2 have never been opened. These figures did not cover all of the States nor all of the railroads having bridges over navigable waters. The highway manager insist on less high bridges and closing of many drawbridges."

9. Commission on Organization of the Executive Branch of the Government, Task Force Report on Water Resources and Power, June 1955, Vol. I, pp. 101-102. The task force recommendation provides that the Congress should "enact legislation to direct that proper consideration be given to forms of transportation other than navigation in establishing the height and width of bridge clearances and in fixing requirements for the construction and operation of movable span bridges." For other task force statements dealing with bridge clearances, see the same report, Vol. I, pp. 11-12, 133-134, 221-223; and Vol. II, pp. 897, 924-928, 946-947, 953-954.

10. For ealier statements of the author concerning the new concept and the advent of this new era, see "Navigation Clearance Requirements for Highway Bridges," AASHO 1952 Convention Group Meetings, p. 28, and "A

Current Look at the Navigational Clearance Problem," AASHO 1953 Convention Group Meetings, p. 19.

11. For a review of the scientific approach used by the Department of Commerce in its study see statements of Mr. Paul F. Royster, Assistant to Under Secretary of Commerce for Transportation, U. S. Department of Commerce, in his paper on "Fair Play in Navigational Clearances for Bridges," American Highways, April 1955, p. 4.

12. As indicated in the text this proposal applies to watercraft which navigate channels having an existing or authorized depth of not more than 12 feet. The craft to be studied in detail—those having fixed projections which extend 20 feet or more above water—represent about 20 percent of the total number of craft in this category. For example of 9,953 watercraft listed in Corps of Engineers Transportation Series No. 4, 1951 edition, only 1,780 (or 18 percent) would be studied in detail. For additional information, see Navigational Clearance Requirements for Highway and Railroad Bridges, op. cit., pp. 49-82.

    With respect to the craft suggested for detailed analysis, information is needed on the feasibility and cost of hinged or telescopic devices (including telescopic pilothouses) and on the monetary effect of such adaptations on watercraft operations. Information also is needed to ascertain the extent of economic losses that might result if fixed bridges restrict the operations of a few watercraft which have projections that cannot be modified. The evidence should show how and to what extent these losses are reflected in overall transportation costs.

13. This situation can be illustrated by developments concerning navigational clearances for highway bridges across the Potomac River. In setting forth its requirements for inclusion in the Commerce report, the U. S. Coast Guard pointed out that the craft it normally uses for maintenance of bouys in the channel require a vertical clearance of 97 feet.

    At the public hearings held by the Corps of Engineers, on May 10, 1955, concerning the reasonableness of the 25-foot vertical navigational clearance proposed for the Constitution Avenue Bridge as a fixed structure, the District of Columbia pointed out that inclusion of a movable span for accommodation of craft requiring extreme vertical clearances would increase the construction cost of the bridge $1,900,000. The record also revealed that a similar increase in construction costs, estimated at $1,500,000, would be expected on the anticipated replacement structure for the Old Highway Bridge, if a movable span should be required there. Annual costs of maintaining and operation of the movable spans also would be involved.

    The representative of the U. S. Coast Guard at this hearing advised that by changing the type of bouys in the channel upstream from the proposed bridge, his agency could provide its services with craft that can be accommodated under the proposed bridge at an estimated increase in its operating costs of $1,000 a year, a very nominal sum indeed.

    A similar situation existed early this year with respect to the application of the State of Minnesota for a permit to construct a fixed bridge across the Minnesota River on Trunk Highway No. 65 (Lyndale Avenue).

Construction of the bridge is being financed with State and Federal-aid monies. When the application was being considered, the Second Coast Guard District recommended a vertical clearance of 50 feet above pool elevation. According to an economic analysis made by the Corps of Engineers, the vertical clearance required by the Coast Guard cutter serving the Minnesota River could be reduced by lowering the radio mast on the craft.

Since public funds pay both for highway bridges and for providing aids to navigation, a realistic nationwide evaluation of this problem does affect the public interest.

14. Seagoing vessels require lights which conform to the International Rules of the Road. International Rule 2(a)(iii) refers to the height of such lights. Under this rule certain seagoing vessels capable of navigating inland and intracoastal waterways having a depth of 12 feet or less are required to display navigational lights at heights up to 75 feet above water. The number of craft in this category, and related details, should be made public. The rule reads:

> "These two white lights shall be so placed in a line with and over the keel that one shall be at least 15 feet higher than the other and in such a position that the lower light shall be forward of the upper one. The horizontal distance between the two white lights shall be at least three times the vertical distance. The lower of these two white lights or, if only one is carried, then that light, shall be placed at a height above the hull of not less than 20 feet, and, if the breadth of the vessel exceeds 20 feet, then at a height above the hull not less than such breadth, so however that the light need not be placed at a greater height above the hull than 40 feet. In all circumstances the light or lights, as the case may be, shall be so placed as to be clear of and above all other lights and obstructing superstructures."

Related Inland Rules read:

> "Art. 2. A steam vessel when under way shall carry—(a) On or in the front of the foremast, or if a vessel without a foremast, then in the fore part of the vessel, a bright white light so constructed as to show an unbroken light over an arc of the horizon of twenty points of the compass, so fixed as to throw the light ten points on each side of the vessel, namely, from right ahead to two points abaft the beam on either side, and of such a character as to be visible at a distance of at least five miles.
>
> "(e) A seagoing steam vessel when under way may carry an additional white light similar in construction to the light mentioned in subdivision (a). These two lights shall be so placed in line with the keel that one shall be at least fifteen feet higher than the other, and in such a position with reference to each other that the lower light shall be forward of the upper one. The vertical distance between these lights shall be less than the horizontal distance.
>
> "(f) All steam vessels (except seagoing vessels and ferryboats), shall carry in addition to green and red lights required by article two (b), (c), and screens as required by article two (d), a central range of two white lights; the after light being carried at an elevation at least

fifteen feet above the light at the head of the vessel. The headlights shall be so constructed as to show an unbroken light through twenty points of the compass, namely, from right ahead to two points abaft the beam on either side of the vessel, and the after light so as to show all around the horizon."

Rule No. 5 of the Pilot Rules for the Western Rivers and the Red River of the North requires that a seagoing vessel underway shall carry lights as required by article 2, International Rules, as amended. Rule No. 7 of the former reads:

"(a) A steam vessel underway, except as otherwise provided in these rules, shall carry, in addition to side lights as described in rule 3 (a), (b), and (c), a central range of two white lights, the after light being carried at an elevation higher than the light at the head of the vessel. The headlight shall be so constructed as to show an unbroken light through twenty points of the compass, namely, from right ahead to two points abaft the beam on either side of the vessel, and the after light so as to show all around the horizon.

"(b) The lights for barges, canal boats, scows, and other vessels of nondescript type, when in tow of steam vessels, and for ferryboats, shall be as prescribed by the Commandant, United States Coast Guard."

Rules 3 (a) and (e) of the Pilot Rules for the Great Lakes and their connecting and tributary waterways and the St. Mary's River read:

"Rule 3. Except in the cases hereinafter expressly provided for, a steam vessel when under way shall carry:

"(a) On or in front of the foremast, or if a vessel without a foremast, then in the fore part of the vessel, a bright white light so constructed as to show an unbroken light over an arc of the horizon of twenty points of the compass, so fixed as to throw the light ten points on each side of the vessel, namely, from right ahead to two points abaft the beam on either side, and of such a character as to be visible at a distance of at least five miles. Such light shall be at a greater height above the water than the side lights required by subdivisions (b) and (c).

"(e) A steamer of over 100 feet register length shall carry also, when under way, a bright white light so fixed as to throw the light all around the horizon, and of such a character as to be visible at a distance of at least three miles. Such light shall be placed in line with the keel at least 15 feet higher than, and more than 50 feet abaft, the light mentioned in subdivision (a) of this rule; or in lieu thereof two such lights of the same character and height as herein described placed not over 30 inches apart horizontally, one on either side of the keel, and so arranged that one or the other or both shall be visible from any angle of approach."

15. It is conceivable that in such cases a telescopic mast or telescopic tower might be more practical than a hinged mast. To ascertain what can be accomplished here one need merely explore some of the latest developments in communications media.

16. On page 50 of the Commerce report, a summary of watercraft of American registry (except fishing craft and pleasure craft) that use the Gulf Intracoastal Waterway and the Mississippi River System—reveals that out of

9,953 craft listed only 1,880—or 18 percent of the total—have fixed projections of 20 feet or more above water when the craft are light. Only 79 watercraft—less than one percent of the total—have fixed projections which extend 60 feet or more above water. According to the Commerce report, page 85, the Department of the Navy indicates it needs a vertical clearance of 59 feet across this waterway. On page 90, the U. S. Coast Guard indicates its maximum as 61 feet, with lower clearances required on certain portions of the waterway. Yet, the minimum vertical navigational clearance for fixed bridges across the Gulf Intracoastal Waterway is 73 feet.

The evidence demonstrates beyond question that the minimum standard vertical navigational clearance for bridges across this waterway is intended to serve the extremes in waterway traffic, including floating construction equipment having extreme projections not essential for movement of the craft. The evidence also shows that—insofar as this waterway is concerned—only a relatively few watercraft need to be studied in detail to arrive at an evaluation of the effect of a lower vertical clearance for fixed bridges upon waterway transportation costs. Data concerning the number and characteristics of fishing craft and pleasure craft operating on these waterways also can and should be obtained.

17. Navigational Clearance Requirements for Highway and Railroad Bridges, op. cit., page 47, illustrates savings in the City of Chicago. Also see "Are Movable Spans Economically Justified," The American City, September 1955, pp. 152-154.

18. The Commerce report, pp. 51-79, discusses feasible adaptations and the standardization of equipment.

19. Such a study is being suggested because proposals have been made in the past that a bridge might be constructed across a given waterway without regard to navigational needs, if the owner of the proposed bridge would acquire the riparian rights of owners of lands contiguous to the waterway and upstream from the proposed bridge. Summarized briefly, riparian rights give to the owner of land contiguous to a navigable waterway the right (a) to reasonable use of the water passing his property; (b) to the flow of water past his property subject to reasonable use by other riparian owners; and (c) of access to the waterway, including use of his banks and construction of wharfs. These rights are subject to a paramount right—the public right of navigation which, incidentally, is not a property right. It would seem, therefore, that the Congress may extinguish the public right of navigation on a given reach of waterway without affecting the riparian rights of a landowner. This could be accomplished by a grant of authority to construct a bridge without regard to navigational needs, or by a formal declaration that the reach of waterway is not navigable (which automatically would permit construction of a bridge without regard to navigational needs). From a preliminary review of court decisions on this subject, it appears that under the Federal constitution there is no requirement that a landowner be compensated because the public right of navigation in front of his property, or downstream therefrom, has been extinguished.

20. The Lyndale Avenue Bridge, cited in footnote No. 6, is an example where a similar method was used.

21. The relative merit of such a shift in the location of a waterway terminal can be recognized, for example, where the watercraft which require excessive bridge clearances carry petroleum products. If the cost of establishing and operating a waterway terminal at a point below existing or prospective bridges—downstream from an established terminal—and the cost of pumping petroleum products to the upstream storage plant, are less than the bridge costs required for continued waterway movement of these products on craft which require excessive bridge clearances, obviously the bridge clearances should not be required.

    A situation illustrating this condition exists on the Potomac River in Washington, D. C. On August 23, 1955, the Department of the Army approved the plans for construction of the proposed Constitution Avenue Bridge as a fixed structure with a vertical clearance of 27.5 feet above mean low water. As indicated in footnote 12, this fixed bridge will cost about $1,900,000 less than a movable span bridge at this location. An additional saving of $1,500,000 in construction costs can be expected through proposed use of a fixed bridge as the replacement for the old Highway Bridge, an obsolete swing span. In both instances the need for movable span operating and maintenance costs will be eliminated.

    The vertical navigational clearance approved for the Constitution Avenue Bridge and proposed for the other structure will accommodate barges and tugs moving sand and gravel and certain types of barges and tugs hauling petroleum products. However, the fixed structures will not permit passage of self-propelled barges and petroleum tankers which heretofore navigated this reach of the river. Testimony of waterway interests at the Corps of Engineers hearing, held May 10, 1955, concerning this condition—and their statements that they must rely on the latter type of craft during adverse weather—led to the suggestion that the relative merits of a downstream waterway terminal and pipeline should be explored. The merits of the proposal in this instance is evident by approval of the Constitution Avenue Bridge.

    This illustration is not intended to suggest that the solution may apply solely to waterway movement of petroleum products. Nor is it intended to suggest that the movement of other products can be shifted from waterway to other transportation media as readily and as economically as the movement of petroleum products can be shifted from waterway to pipeline. Nevertheless, the illustration does describe an area of transportation relationships which needs careful study in future bridge clearance decisions.

22. For example, see Navigational Clearance Requirements for Highway and Railroad Bridges, op. cit., pp. 156-157, or 33 United States Codes, Sect. 21-46.

23. The Acts of the 84th Congress declaring nonnavigable certain waterways in Connecticut are intended to facilitate economical construction of different sections of Greenwich Killingly Expressway across waterways heretofore deemed navigable. The enactments eliminate the need for considering navigational clearances in proposed highway structures.

    Public Law 152(S.1300) declared nonnavigable approximately 500 feet of an arm of Greenwich harbor. Most of the area was unimproved and at low tide it is only a salt marsh flat. Under the terms of the Act, the State is

to dredge nine-tenths of an acre in a different section of the harbor to compensate for a similar area that fell within the harbor area and had to be abandoned.

Public Law 151(S.1469) declared nonnavigable about 775 feet of the improved channel in the west branch of Cedar Creed, a part of the Bridgeport harbor. It also abandoned a previously authorized Federal navigation project that involved a channel 18 feet deep and 100 feet wide. Establishment of the new bulkhead and pierhead line resulted in the loss of navigation rights to some five firms. The Department of the Army interposed no objection to the passage of the Act provided land and riparian rights would be acquired and navigational requirements eliminated. The State agreed to acquire the riparian right of all owners of uplands which border the affected area.

Public Law 289(S. 2514) declared about 2,100 feet of the improved channel in West River, a part of New Haven harbor, a nonnavigable waterway. It also authorized abandonment of the Federal navigation project, which had a channel 12 feet deep with width ranging from 75 feet to 150 feet. Establishment of the new bulkhead and pierhead line resulted in loss of navigation rights to one firm, which shipped 8 cargoes in 1953, totaling 1,600 tons, and 10 cargoes in 1954, totaling 2,000 tons. About $46,000 had been expended in improvement and maintenance of the portion of the channel being abandoned. The State acquired title to all upland properties having riparian rights.

24. Public Law 169(S. 1250) 84th Congress, declared Pike Creek above the easterly side of the highway bridge at Sixth Avenue, Kenosha, Wisconsin, a nonnavigable stream. The enactment has enabled the city to reclaim and develop about 3 1/2 acres for commercial purposes and to permit extension of a major business street across the filled area. The Department of the Army interposed no objection to the bill.

25. Public Law 34(H.R. 1816) 84th Congress, declared nonnavigable the portion of the tidewaters in Fort Point Channel and South Bay, Boston, Massachusetts, which lies above the highway bridge at Dorchester Avenue. This law permits construction of the John F. Fitzgerald Expressway across these waterways without a drawspan and permanent closure of three existing movable bridges over these waters. The legislation was requested by the Massachusetts Department of Public Works and was prepared in cooperation with the Corps of Engineers. According to the Massachusetts public works commissioner, only a negligible amount of waterborne traffic had been using this waterway and the navigational facilities therein were greatly dilapidated.

The waterway was used principally by the City of Boston, for refuse disposal scows. The city is planning refuse-disposal facilities that will not require use of the scows. Of two other current users of the waterway, one was a lumber company that received only 7 to 10 boatloads annually, and the other was a scrap iron dealer having about two waterway shipments a year.

In addition to unreported savings that would have been expended for constructing and maintaining movable span bridges (or high-level bridges) for accommodation of navigation, closure of the existing drawbridges saves about $150,000 annually. At an interest rate of 3 percent per annum, the latter sum would require an investment of $5,000,000.

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BRIDGE CLEARANCE: PROBLEM NEEDS REALISTIC APPROACH

William E. Cleary[1]
(Proc. Paper 937)

FOREWORD

This paper is one of a group of five concerned with certain phases of the physical characteristics of bridges crossing waterways as they affect water and land traffic. All were presented at the Annual Convention of the ASCE in New York on October 24, 1955.

The symposium arose from a concurrent growing awareness on the part of engineers concerned with waterway, highway, and railroad traffic of the need for rationalizing any extreme views as to appropriate navigation clearances. In the first of these papers "Bridge Clearances: Policies and Practice" (Proc. Paper 935) Eugene W. Weber traces the evolution of the bridge-clearance problem and discusses existing law and practice toward realization of reasonable clearance requirements from the standpoint of all affected forms of transport. "Bridge Clearances: The Interest of the Bureau of Public Roads" (Proc. Paper 936) Walter Kurylo presents the view that navigation clearances of bridges should be based on the least overall cost to the public and studies should be made to determine the most economic solution. William E. Cleary in "Bridge Clearances: Need for Realistic Approach" (Proc. Paper 937) states the position of the waterway operators as opposed to "standard clearances" and emphasizes the need for a cooperative and reasonable approach to the problem. The paper "Bridge Clearances: The Operator's View" (Proc. Paper 938) by N. L. Caruthers, emphasizes the importance of navigational clearances to rational economic development and water transportation, and stresses the need of cooperative and realistic approach to the problem. The last paper by E. E. Dittbrenner "Bridge Clearances: Problems in Northeastern United States" (Proc. Paper 939) describes the industries, resources, and transportation and their proper coordination and integration.

With an impending national highway program of unprecedented magnitudes

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1. Executive Vice-Pres., The New York Tow Boat Exchange and Harbor Carriers of the Port of New York, New York, N. Y.; also Regional Representative, North Atlantic Region, The American Waterways Operators, Inc.

these papers have timely significance in their effect upon adequacy of clearances and cost of bridge construction.

SYNOPSIS

Operators of craft on the inland waterways of the United States recognize the need for a practical approach to the problem of bridge clearances and desire to cooperate in arriving at satisfactory solutions. The author cites the agreement reached between navigational and other interests, relative to clearances along the Connecticut Expressway, as an example. He feels that any standardized formula applied to all waterways would jeopardize waterborne commerce and that each crossing should be considered on its own merits.

The operators of towboats, barges and shallow-draught motor tankers on the more than 28,000 miles of navigable rivers, harbors and canalized inland waterways of the United States clearly recognize the urgent need for a practical and realistic approach by navigation interests to the problem of horizontal and vertical clearances on railroad and highway bridges constructed over those waterways.

While the construction of railroad bridges has remained fairly static in recent years, the tremendous increase in the number of licensed motor vehicles, both for commercial and pleasure purposes, has necessitated a very comprehensive highway building program, with a resultant number of river crossings to be constructed incident thereto.

We have most certainly become a "Nation on wheels," and, indeed, a Nation on "high speed wheels." All over the Country we see the relocation and improvement of trunk highways and feeder roads. More particularly we note the construction in State after State of the so-called "Turnpikes," "Thruways" or "Expressways," which are toll roads constructed without the aid of Federal funds.

These "Expressways" are geared to a high speed, uninterrupted flow of vehicular traffic. The thoughts of a drawspan over a navigable waterway at any point on an arterial high-speed road brings shudders to the engineers who quite naturally envision only fixed bridges to accommodate a heavy density traffic pattern moving swiftly and without interruption.

With fixed bridges being the "order of the day," the inevitable controversy arises between the navigation interests who seek clearances considered adequate and reasonable for the present and future needs of water-borne commerce, and the agencies responsible for the design and construction of the bridges who are naturally seeking to reduce costs and minimize engineering difficulties.

The navigation interests have in the past been charged with being reactionary and arbitrary in their thinking in regard to demands for excessive and unwarranted vertical and horizontal bridge clearances. While it may be true that in isolated cases there may have been some unrealistic and selfish thinking on the part of individual vessel operators, we hold that Organizations such as ours who represent the marine industry collectively have a creditable record along these lines, particularly in recent years.

Our people well realize that each additional foot of clearance, especially

vertical clearance, adds very substantially to the cost of the construction of any bridge and may well add considerably to the complexity of the engineering problems to be solved in putting up the bridge.

We are totally sympathetic with the desire of the designers and constructors of these bridges to hold such costs and engineering difficulties to the irreducible minimum.

However, the public right of navigation, i.e., the right to proceed from place to place by water without unreasonable interference, has been clearly recognized by statute, practice and custom since the earliest days of our Country. The proper exercise of this inalienable right is just as much in the public interest as is the economical construction of highway and railroad bridges.

The ever increasing awareness by industry of the benefits of cheap water transportation of raw materials and finished goods has resulted in a tremendous upsurge in the construction of industrial plants, powerhouses and factories along the banks of navigable waterways, particularly in the great mid-continent area.

If industry is to grow and prosper, with resultant benefits to all the people, it must not be throttled by unreasonable restrictions upon waterborne movements of raw materials and finished products.

While all efforts have been made to keep this presentation general and non-technical in nature, we think it no harm to point out that traffic on the inland waterways has been built up by agricultural and industrial shippers of bulk cargoes (fuels, basic raw materials and products) to the point where the eleven principal navigation channels are saving the shippers in transportation costs more than double the total of 1) amortization of the cost of construction, 2) interest on the nation's investment in the channels and, 3) the cost of maintenance and operation. One channel reports a ratio of benefits to costs of 14.8 to one.

We find the following ratios of benefits to costs prevailing on eleven principal waterways. (For example, the benefit to cost ratio of 14.8 on the Gulf Intracoastal Waterway indicates the benefits are the equivalent of 14.8 times the annual charges for interest, amortization, maintenance and operation in 1953.)

	Ratio of Benefits to Costs Counting Costs as I	
	1953	1948
Gulf Intracoastal Waterway	14.8	13.5
Lower Mississippi River	9.5	5.
Monongahela River	9.4	14.5
Illinois Waterway	8.1	5.7
Ohio River	7.3	4.1
Middle Mississippi River	4.4	3.4
Cumberland River	3.6	1.8
Warrior-Tombigbee Waterway	3.1	1.9
Kanawha River	2.9	1.9
New York State Barge Canal System	2.2	2.2
Upper Mississippi River	2.1	1.4

This computation was based, by the Army Corps of Engineers, on direct savings in transportation costs or the difference between economical barge rates and the rates of competing carriers. Not included were additional savings to shippers through water-compelled railroad freight rates, which are lower than the rail rates would be if barge competition did not exist. Another economy for the shipper effected by barge transport is the differential in handling costs of bulk commodities. It is easier, cheaper and faster to load or unload one 1000-ton coal barge than twenty-five 40-ton coal cars or one one-million-gallon oil barge than 100 ten-thousand-gallon tank cars.

The tug, barge and shallow-draught motor tanker operators have indeed been endeavoring to cooperate wholeheartedly with railroad and highway interests in an effort to amicably work out reasonable and mutually acceptable vertical and horizontal navigational clearances on new bridges.

We are glad to say that these efforts have proven very successful and, with an increasingly greater understanding and recognition by all interests of the problems of the other parties involved, we look forward to an enlightened and constructive approach to these problems in the future.

The vessel operators in the northeastern part of the United States have reason to point with pride to their record in such matters, a particular and timely example of which might well be noted in the series of compromises leading to the fixing by agreement of all navigational clearances on the many fixed bridges spanning the numerous rivers with a high marine traffic density pattern along the route of the $400,000,000 Connecticut Expressway, now in the process of construction.

The cooperative and reasonable approach to this matter by the navigation interests, acting through the Organizations which the writer has the honor to represent, has been categorically acknowledged through laudatory letters received by us from the Commissioner of the Connecticut State Highway Department.

Much has been accomplished through this laudable, if perhaps new-found spirit of cooperation between the navigation interests and the bridge builders, but admittedly much still remains to be done.

Vessel owners have been earnestly exploring the possibilities of the modification of the physical characteristics of their vessels so as to provide for the retraction, where feasible, of fixed projections above the normal superstructure of tugs, barges and motor tankers so as to reduce the vertical clearance requirements.

This in theory sounds absurdly simple and, to those unfamiliar with the practical aspects of vessel construction and operation, the caution with which the navigation interests have approached this matter appears to border on the reactionary.

However, when one takes a long look at the myriad of difficult problems involved in an industry-wide program of structural modification of the physical characteristics of vessels, the matter cannot be dismissed so lightly.

Historically, the waterway transportation people have operated on a slender margin of profit in order to attract the freight which they are inherently best capable of transporting. High shipyard costs of such a widespread modification program could very well be a very serious factor in the competitive picture.

In fact, despite the claims of objectivity made by some of those clamoring for a reduction of navigational clearances as being in the so-called "public interest," it may very well be that the real reason behind their apparent

altruism is a self-serving attempt to boost the cost of water transportation through additional construction and operational requirements to the eventual benefit of the competing forms of surface transportation, but also to the detriment of the shipper and consumer.

Leaving the cost factor aside, very grave doubts have arisen in the minds of many responsible and progressive vessel operators as to the safety of collapsible and retractable masts, radar antenna and other navigational appurtenances required when a vessel is operated interchangeably in "inland" and "off shore" commerce.

The regulations, both by statute and by promulgation, covering the display of certain lights are so rigid and inflexible as to make the heights of light-supporting masts entirely beyond the control of the vessel owner.

With vessels operating alternatively under "inland" and "international" rules, it is interesting to note the official position of the United States Coast Guard in this matter.

The Coast Guard comment, which speaks for itself, is as follows:

> "It might be possible to design, modify, or adjust vertical fixtures extending above the superstructures of watercraft, however, it may not be practical or safe for masts, radars, smokestacks, kingposts, antennas, etc., to be unstepped or collapsed."
>
> "The possibility also exists that the vessels, after such alterations, might violate certain provisions of the statutory international and inland Rules to Prevent Collisions of Vessels, which require that navigational lights of water-craft be placed at certain specified heights. Vessels altered in accordance with (the) conclusions *****, while operating at night might be required to alter the normal position of their navigational lights in order to pass beneath an overhead obstruction. This would be a technical violation of the aforesaid Rules. In event of collision in such case, it is quite possible that civil liability would be predicated on the failure to show proper navigational lights at the time of casualty."

However, in the interests of good cooperation, the marine industry is not overlooking any possibilities along these lines and we are glad to report that considerable progress has already been made in lowering fixed objects, either permanently or by retraction, so as to minimize vertical clearance requirements.

The problems to be solved on bridge construction clearances vary so markedly with the location of the structure, the nature and volume of the traffic on the waterway and other local conditions that we feel that each crossing must be considered on its own merits, a practice long followed by the Corps of Engineers, U. S. Army, in granting applications for the construction of any bridge over a navigable waterway.

The navigation interests are definitely and unalterably opposed to the setting up of constrictive so-called "standardization" formulae, which, while seemingly inoccuous on the surface, would be a lethal weapon pointed at the throat of waterborne commerce.

We pledge a cooperative and reasonable approach to the whole problem of navigational clearances, but feel such matters should continue, as in the past, to be determined through the machinery set up by the Corps of Engineers.

The policies of the Corps, as more particularly set forth in the "STATEMENT OF POLICY, PRACTICE AND PROCEDURE ON BRIDGES," issued under date of November 3rd, 1954 by the Office of the Chief of Engineers,

Department of the Army, Washington, D. C., act as a continuing safeguard of the rights of navigation and other forms of surface transportation alike, with resultant benefits to all of the people of the United States. This statement of policy is given in Appendix A to this paper.

APPENDIX A

DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF ENGINEERS
WASHINGTON 25, D. C.

November 3, 1954

BRIDGES
STATEMENT OF POLICY, PRACTICE AND PROCEDURE

The purpose of this statement is to set forth the policy, practice and procedure of the Corps of Engineers in administering Federal laws governing the construction of bridges over navigable waters, to establish a clear and mutual understanding among all interested parties, and to serve as a basis for cooperation in achieving fair and reasonable application of the laws.

1) Paramount Right of Navigation. It is essential that there be a clear derstanding as to the distinction between the paramount right of navigation and what has sometimes been termed the paramount right of vessels over land traffic, but which is actually the public right of navigation.

Insofar as the subject of bridging navigable waters is concerned, a distinction must be clearly drawn between, first, the paramount right of navigation as against the right of property, and second, the public right of navigating as against transportation by any other means. Both will be discussed below and it will be seen that the first has little or no relation to the subject. The second is, of course, pertinent and a clear and mutual understanding of the matter is of greatest importance in establishing a common ground of approach to the problem of constructing a bridge over a navigable water. There are both public and private rights in navigable waters and the beds of those waters—the right of navigation and the right of property. It is the settled law of this country that the States own the beds of navigable waters unless they have been granted away, and that this title is held subject to the paramount right of navigation, the regulation of which, in respect to interstate and foreign commerce, has been granted to the United States in Article I, section 8, of the Constitution. The public right of navigation is a right of way or passage. As a public right it is the right which every one of the public has to go from place to place by water without any unreasonable interference on the part of any person. The only absolute element in the right is a reasonable opportunity to reach an objective point.

Although the public right of navigation takes precedence over the private right of property, transportation by water does not take precedence over and is not paramount to transportation by any other means. On this point the Supreme Count of the United States in The State of Pennsylvania, complainant, v. The Wheeling-Belmont Bridge Company (13 Howard 518) said "The right of navigating the Ohio River or any other river in our country, does not necessarily conflict with the right of bridging it. But these rights can only be maintained when they are so exercised as not to be incompatible with each other. It is in their improper exercise, and not in their nature, that any incompatibility exists." And in Escanaba Company v. Chicago (107 U.S. 678) "It (the complainant) insists that the navigation of the river and its branches should

not be thus delayed; and that the rights of commerce by vessels are paramount to the rights of commerce by any other way. But in this view the complainant is in error. The rights of each class are to be enjoyed without invasion of the equal rights of others. Some concession must be made on every side for the convenience and the harmonious pursuit of different occupations."

The duty of the Department under Federal law is to prevent unreasonable obstructions to navigation, and in performing this duty the Department is acutely aware that it must weigh all conflicting interests and have respect for the cost of things.

2) Navigable Waters. The navigable status of a stream is a question of fact which can be conclusively determined only by the Courts. The Corps is not the judge of navigability, but it can and does exercise proper discretion in acting upon applications for permission to place structures in or over waters that may be legally navigable but not actually navigated. The Corps has no desire to burden itself with the consideration of cases in which navigation has no interest, nor to require clearances for navigation where no navigation exists. In such cases the Corps generally advises as to clearances considered desirable for the safety of the bridge during high water stages.

3) Public Hearings on Bridge Applications. Under long established policy, the Corps of Engineers issues a public notice of every application. If the waterway is important, or if opposition develops, a public hearing is held. Frequently a conference of opposing interests is held by a District Engineer in order to work out a mutually agreeable compromise. The hearings are informal, no one is subjected to examination or cross-examination, and while the public record is supplemented by the Department's studies, perceptions and judgments, the greatest reliance is placed on the evidence obtained at public hearing. The Corps is aware of its serious responsibility in approving the location and plans of a bridge. It realizes the cost of things, and it is conscious of the fact that the injury, if there be one, to either land or water interests, is as permanent as the work it authorizes or requires. To insure the rendering of fair and impartial decisions the Corps maintains and develops records, data, and statistics with trained personnel, but it has always sought the views of all interests affected.

In order to develop the greatest value from public hearings and records the following must be observed:

a) The decision as to whether a hearing should be held should be made only after consultation with the applicant and principal navigation interests.

b) The facts determined by the District Engineer from his preliminary investigation of the application and site of the bridge should be presented at the hearing for scrutiny, testing, or rebuttal by interested parties.

c) While no direct examination or cross-examination occurs all parties should be encouraged to direct any question to the presiding officer for relay in order to develop pertinent facts.

d) The presiding officer should make every effort to have controversial points fully evidenced and developed either at the hearing or by supplementary letters, statements, or briefs.

e) Any supplementary evidence received after hearing should be furnished to the opposite side for information and any desired comment.

f) Emphasis should be placed on a factual and public discussion of controversial issues, notably the requirements of extremes of navigation such as extreme vessel heights involving a limited number of craft, and navigation at extreme river stages.

g) Whenever possible the effect of any point of issue should be established in terms of costs and benefits occasioned the opposing interests to permit determination of the reasonableness of demands or proposals.

h) Finally, the hearing should be open to discussion not only of maximum clearances, but also to any lesser clearances that might be found practical.

4) Finding of Fact. The final decision of the Department is represented by the instrument of approval, or denial of an application. Preparation of opinions or findings of fact have not been the practice, because, although hearings are held, they are part of an investigatory process and decisions rest upon the whole investigation rather than merely upon that portion of it embraced by the hearing.

Notwithstanding the above, some bridge owners have expressed the feeling that issues invariably have been resolved in favor of navigation. The record does not support this, but the misapprehension is appreciated and can be resolved by preparation of a Findings of Fact to accompany decisions in any controversial case.

The requirement of an opinion will provide considerable assurance to all that the case will be thought through by the deciding authorities. There is a salutary descipline in formulating the basis for a result, a discipline that might be absent where there is freedom to announce a naked conclusion. Error and carelessness must be eliminated in the opinion-shaping process. The exposure to public scrutiny and criticism is healthy. The parties to a proceeding will be better assured if they are enabled to know the basis of the decision affecting them.

The Findings of Fact will be prepared by the District Engineer and will include the factual matter now contained in his present form of report as well as the basis for action recommended. The Findings of Fact will be attached to and be a part of each instrument or denial, and should be furnished to any interested party upon request.

5) Standard Bridge or Guide Clearances. From time to time, boards have been created to study and recommend standard clearances for a waterway, or group of related waterways. The procedure in each case has been the same: a public hearing to afford all interested parties an opportunity to be heard, the collection of all available data and a consideration of prospective development of the region. The purpose of the clearances thus established is to furnish a guide not only to bridge owners in bridge planning, but also to navigation interests for standardization of their equipment.

It is the policy of the Chief of Engineers to maintain, to revise whenever necessary, and to extend the present system to cover as far as practical and necessary all navigable waters of the United States. In the process, bridge owners, navigation interests, state waterway officials, port authorities and State and local governments will be consulted and requested to take an active part. The aim will be a coordinated waterway, river basin, and nation wide system with a minimum number of standard or guide clearances.

6) Drawbridge regulations. Existing Federal law authorizes the Secretary of the Army to prescribe such rules and regulations as "the public interests require" to govern the operation of drawbridges (33 U.S.C. 499). In the absence of such regulations a drawspan is required to be opened promptly upon signal from a vessel. Regulations prescribed by the Secretary of the Army are contained in Part 203, Title 33 of the Code of Federal Regulations and also in a pamphlet published by the Corps of Engineers.

In practice, applications have been received from owners of drawbridges, where the bridge logs show comparatively few or intermittent openings, requesting regulations for limited operation of the drawspans such as openings only upon advance notice, or restricted openings during observed slack or off-navigation seasons. The public interests are determined by public notice and hearing supplemented by investigation of vessel and land traffic, known bridge openings, and the effect of limited drawspan operation on both types of traffic. Some 700 drawbridges now have regulations allowing limited operation which have proved to meet adequately the needs of navigation and at the same time have served to expedite land traffic and permitted substantial savings to bridge owners.

A survey of all drawbridges over navigable waters recently made by the Corps of Engineers shows the following:

Number of highway drawbridges	1,365
Number of railroad drawbridges	745
Number of combined highway and railroad drawbridges	78
Total	2,188
Number of drawbridges not opened in 1953	424
Number of above 424 not covered by regulations	296

The reasons for non-use of the drawspans were found to be many and varied, but can be summarized as due to changes in types of craft; decline of shipbuilding and repair yards above bridges; decline of industries such as logging; development of land transportation replacing water transportation; and a shifting of water-borne commerce to other ports and waterways. In general, the history of these drawbridges shows that in the main they served their purpose and are now obsolete in a changing economy. An analysis of the ages of these bridges shows that almost one-half are 50 years old, and 85% are more than 25 years old.

Full information is not available whether there is any actual operating cost involved in the drawbridges not now required to be opened or opened only infrequently, but District Engineers will take the initiative in advising bridge owners of the law and that the Department is prepared to accept and will take prompt action on any request for the adoption of special bridge operating regulations. Semi-annual review of movable bridge operations will be made by District Engineers to insure that the full potentialities of special bridge operating regulations are developed for the benefit of the public.

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BRIDGE CLEARANCES: THE OPERATOR'S VIEW

N. L. Caruthers[1]
(Proc. Paper 938)

FOREWORD

This paper is one of a group of five concerned with certain phases of the physical characteristics of bridges crossing waterways as they affect water and land traffic. All were presented at the Annual Convention of the ASCE in New York on October 24, 1955.

The symposium arose from a concurrent growing awareness on the part of engineers concerned with waterway, highway, and railroad traffic of the need for rationalizing any extreme views as to appropriate navigation clearances. In the first of these papers "Bridge Clearances: Policies and Practice" (Proc. Paper 935) Eugene W. Weber traces the evolution of the bridge-clearance problem and discusses existing law and practice toward realization of reasonable clearance requirements from the standpoint of all affected forms of transport. "Bridge Clearances: The Interest of the Bureau of Public Roads" (Proc. Paper 936) Walter Kurylo presents the view that navigation clearances of bridges should be based on the least overall cost to the public and studies should be made to determine the most economic solution. William E. Cleary in "Bridge Clearances: Need for Realistic Approach" (Proc. Paper 937) states the position of the waterway operators as opposed to "standard clearances" and emphasizes the need for a cooperative and reasonable approach to the problem. The paper "Bridge Clearances: The Operator's View" (Proc. Paper 938) by N. L. Caruthers, emphasizes the importance of navigational clearances to rational economic development and water transportation, and stresses the need of cooperative and realistic approach to the problem. The last paper by E. E. Dittbrenner "Bridge Clearances: Problems in Northeastern United States" (Proc. Paper 939) describes the industries, resources, and transportation and their proper coordination and integration.

With an impending national highway program of unprecedented magnitudes these papers have timely significance in their effect upon adequacy of clearances and cost of bridge construction.

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SYNOPSIS

Marine interests have become increasingly aware of the problem of bridge clearances across navigable waterways and recognize the need for a realistic approach to its solution. The increasing amount of waterways traffic, the larger sizes of tows, safety of operations and statutory requirements combine to prevent the adoption of set standards for bridge clearances. The author develops these points to illustrate his thesis that each crossing should be considered on its own merits.

For a number of years marine interests have become increasingly aware of the ever growing and pressing problem relating to bridge clearances across navigable waterways. The need for a realistic approach by navigation interests to meet this issue is clearly recognized.

In the beginning, it may be appropriate to admit that in the past some marine operators have plead for excessive bridge clearances. To ascertain just what mistakes may have been made twenty-five or forty years ago is to engage in hindsight and afterthought and an analysis of the circumstances and facts that prevailed at the time the decisions with respect to such bridge clearances were made.

Much has been said about the continuous and ever increasing growth of land transportation. This growth is a matter of record and with it has come the obvious demand for an extensive highway and bridge building program. It is equally true that the inland waterway industry has experienced a phenomenal growth during the last few years. Despite the fact that waterway transportation is the oldest form of transportation; the waterway transportation industry, as we know it today, is still in its youth. The waterway industry has provided a service geared to the modern needs of the great industries mushrooming all along our waterway system. It is particularly adapted to the efficient, economical movement of the BIG LOAD.

Inland waterways tonnage throughout the nation has shown remarkable increases from nearly seventeen billion ton miles, excluding the Great Lakes area in 1937, to roughly ninety billion ton miles this year. While the national economy expands at the average rate of 4% per annum, the waterways traffic has increased 15% a year since 1946.

The need for greater efficiency has produced new innovations. The size of vessels has been tripled since the period of the great depression. Tows longer than the Queen Mary are now plying our inland waterways. It is obvious, therefore, that the subject of bridge clearances poses a serious problem to navigation interests and to the general public. An unrealistic approach to the problem cannot only greatly hamper present waterway operations, but could very well prevent the development and advent of the most economical form of mass water transportation to entire areas.

Navigation interests are irrevocably opposed to the inauguration of set standards with respect to bridge clearances. We believe any such attempt to be wholly unrealistic and impracticable. Back in 1948, the Corps of Engineers established a general standard to apply to new construction and replacement of bridges across the Gulf Intracoastal Waterway of 73 feet vertical and 125 feet horizontal, but with the definite understanding that such standards were to be considered merely as a guide since each application

should be considered on its own merit. We wholly concur in the belief that every bridge must be considered on its own merit.

As an example, the waterway Operators recently went on record as approving a fixed bridge across the Gulf Intracoastal Waterway with a vertical clearance of 50 feet. This clearance was approved on the premise that there is a reasonable alternate route available for the movement of heavy lift and maintenance equipment. One problem presents itself when an alternate route is available for such equipment and quite another when there is only one access to the area involved. It is quite true that the percentage of this type of equipment is quite small, but this small percentage is of primary importance to our industry. Such facilities are for the waterway industry what the fire engines and ambulances are to the cities in which we live. A sinking in a waterway may well completely obstruct an important channel and we are dependent on this type of operation in such emergencies. The intensive offshore oil drilling program in the Gulf Coast Area necessitates the movement of heavy equipment. It would be the height of folly to permit the construction of low fixed bridges that would hamper this important operation. Similar situations may well exist in various other areas of our nation.

Let's take a look at the progress made on the relatively new Gulf Intracoastal Waterway which reports the highest ratio of benefits to costs of any waterway in our nation. It was not until 1929 that the Engineers started digging the Canal in Louisiana. It was not until June of 1949 that the last link from Corpus Christi, Texas, to Brownsville, Texas, was completed. It was optimistically estimated that this Canal would ultimately develop five million tons of traffic per annum. This little ditch transported nearly forty-four million tons in 1953. World War II caused interruptions of work on many public projects, but it was responsible for the enlargement of this Canal. While tankers were being sunk in sight of the coast by enemy submarines, Navy vessels and military cargos flowed uninterrupted safe from attack. In order to meet the needs of national defense, the dimensions of the waterway were increased from 9 feet x 100 feet to 12 feet x 125 feet in 1942. The need for enlarging the Canal to 16 feet x 300 feet is now being studied by the Corps of Engineers. It is a concluded fact that if low fixed bridges had been permitted to be built across the Gulf Intracoastal Waterway, it could never have developed to the industrial and economical potential that it is today. Some sections of this coast have been transformed from a virtual wilderness to an industrial empire.

It is understood that it is the combination of horizontal and vertical navigational clearances that increase bridge costs. I believe it is generally understood that the horizontal clearance for safe navigation depends on the location of a bridge. So far as horizontal clearance is concerned, safe navigation depends on such factors as the width and depth of a waterway, currents of considerable velocity or whether the waterway traverses open waterways such as lakes, bays and sounds, wind action, and various other factors. It is obvious, therefore, that every bridge application should be carefully scrutinized and that horizontal clearances should be determined by the channel conditions prevailing at a particular location.

The report prepared by the Office of the Under Secretary of Commerce for Transportation entitled "Navigational Clearance Requirements for Highway and Railroad Bridges"—February 1955, appears to be primarily concerned with the problem of vertical clearances for fixed bridges. Navigation interests would certainly prefer fixed bridges provided such structures do

not unreasonably obstruct navigation. Particularly is this true on such confined waterways as the Gulf Intracoastal Waterway where such facilities may be built with the piers placed on the banks of the channel.

In the question of fixed structures over navigable waterways, we must take into consideration that the clearances afforded are those we may have to live with for the next three-quarters of a century. As stated previously, tows have increased enormously within the last few years. The most important tool at a pilot's command is his vision and his ability to judge distance. By way of illustration, in operating a small tow 600 feet in length, when towing empty house barges protruding 17 feet above the waterline with the pilot house 35 feet in height, the channel buoys will disappear from sight 540 feet ahead of the tow. This same tow, with the pilot house 45 feet above the waterline, the buoys will disappear from the line of vision 355 feet ahead of the tow. In the operation of a tow 1000 feet in length (longer tows are being operated), when the pilot house is 35 feet in height, the vision disappears 865 feet ahead of the tow and when 45 feet in height, the pilot loses sight of the buoys 595 feet ahead of the tow. The effectiveness of radar coincides with the line of vision.

Much attention has been given to the feasibility of adjusting water craft projections such as radio and radar antennas, masts and other navigation appurtenances. Some of these problems may be readily solved. Others confronting us present a maze of difficulties. For example, the display of lights is covered by statute and this question can only be solved by legislative action. The safety factors involved in such adjustments deserve the most careful scrutiny. These problems are being earnestly explored by the Operators.

The impressive record of the Corps of Engineers needs no embellishment here. We earnestly believe that theirs is the only agency qualified by long years of experience to capably administer Federal laws governing the construction of bridges over navigable waters.

It is the sincere desire of the Operators to cooperate to the fullest extent in working out an amicable and mutually satisfactory solution to this important problem. Much has been accomplished in this direction; particularly, since the organization just ten years ago last August of The American Waterways Operators, Inc., the National Association of the towboat and barging industry. Bridge Committees have been functioning in this Association, as well as other associations, to deal with this problem in various areas throughout the nation and to arrive at a realistic approach to bridge clearances.

In conclusion, it should be emphasized that much has already been accomplished by virtue of meetings attended by waterway operators and Department of Highway officials of various states with respect to this subject. It is believed that the realistic approach to this problem is to encourage, and can only be achieved, by this cooperative action on the part of all concerned, with all parties approaching the subject with an open mind. These Committees, or representatives of these various organizations, will be more than happy to meet with Highway Department officials or representatives of any other interested agencies or parties involved.

In response to one offer of cooperative action, a prominent State Bridge Engineer replied as follows:

"Certainly any effort to approach this problem with an attitude of understanding and mutual respect on both sides cannot help but be beneficial to both our respective organizations."

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BRIDGE CLEARANCES: PROBLEMS IN NORTHEASTERN UNITED STATES

Erhard E. Dittbrenner,[1] M. ASCE
(Proc. Paper 939)

FOREWORD

This paper is one of a group of five concerned with certain phases of the physical characteristics of bridges crossing waterways as they affect water and land traffic. All were presented at the Annual Convention of the ASCE in New York on October 24, 1955.

The symposium arose from a concurrent growing awareness on the part of engineers concerned with waterway, highway, and railroad traffic of the need for rationalizing any extreme views as to appropriate navigation clearances. In the first of these papers "Bridge Clearances: Policies and Practice" (Proc. Paper 935) Eugene W. Weber, traces the evolution of the bridge-clearance problem and discusses existing law and practice toward realization of reasonable clearance requirements from the standpoint of all affected forms of transport. "Bridge Clearances: The Interest of the Bureau of Public Roads" (Proc. Paper 936) Walter Kurylo presents the view that navigation clearances of bridges should be based on the least overall cost to the public and studies should be made to determine the most economic solution. William E. Cleary in "Bridge Clearances: Need for Realistic Approach" (Proc. Paper 937) states the position of the waterway operators as opposed to "standard clearances" and emphasizes the need for a cooperative and reasonable approach to the problem. The paper "Bridge Clearances: The Operator's View" (Proc. Paper 938) by N. L Caruthers, emphasizes the importance of navigational clearances to rational economic development and water transportation, and stresses the need of cooperative and realistic approach to the problem. The last paper by E. E. Dittbrenner "Bridge Clearances: Problems in Northeastern United States" (Proc. Paper 939) describes the industries, resources, and transportation and their proper coordination and integration.

With an impending national highway program of unprecedented magnitudes

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these papers have timely significance in their effect upon adequacy of clearances and cost of bridge construction.

SYNOPSIS

This paper cites the development of transportation in northeastern United States, particularly New England and New York, and indicates the importance of navigation in the area as a whole, and the role that navigation clearances play in the integration of the several media of transportation. Specific examples are given of marine architecture adopted to minimum clearances, others are cited where regulation could be further used for public benefit. The ineffectiveness of zoning in view of the present concept of navigation rights is illustrated, it is shown that clearance is a problem wherever navigation and land transport exist, and the need for a more complete study of all waterways and watercraft leading to a determination of clearances and navigability are indicated.

INTRODUCTION

It is evident from the preceding papers that there are great differences of opinion, and various shades of evaluation of the many facets involved in the problem. It is well to remind ourselves occasionally that when we approach a matter from a different point of view, we see things differently, and not uncommonly see different things. Only in this way can all the facts be brought out for examination in order to serve as a basis for an objective consensus.

It is the writer's view, that navigation clearances are of great importance because of the role they play in integrating the several media of transportation for the most economical overall cost to the public. They are part of the transportation problem. Being so, perhaps a brief resume of transportation in the northeastern states—generally New England, New York, and New Jersey—will be of value. A great deal of our transportation has developed in this area; its history can illustrate many things of interest to our problem.

Importance of Navigation

The ports in this area dominate the shipping on the Atlantic Ocean, on which 80% of the world's shipping is found. These ports handle one-third of all the waterborne tonnage in the nation—inland rivers, the Great Lakes, coastal, intra-harbor and foreign; and more than half of all the tonnage in all of the nation's seaports. This is graphically illustrated by the chart in Figure 1, where the width of the traffic route shown indicates the amount of shipping using that track.

The region has a seaport on tidewater 150 miles inland giving access to that portion of the "water level route" which is the first break through the Appalachian Mountain system north of its southern end, and traditionally the most important route from the eastern seaboard to the hinterland. Aside from these, there are few important inland waterways in the Region other than estuaries, but its history and present economy are intimately interwoven with navigation in all its phases. Nowhere is navigation more important. The region traditionally has been the nation's workshop, rather sparingly blessed

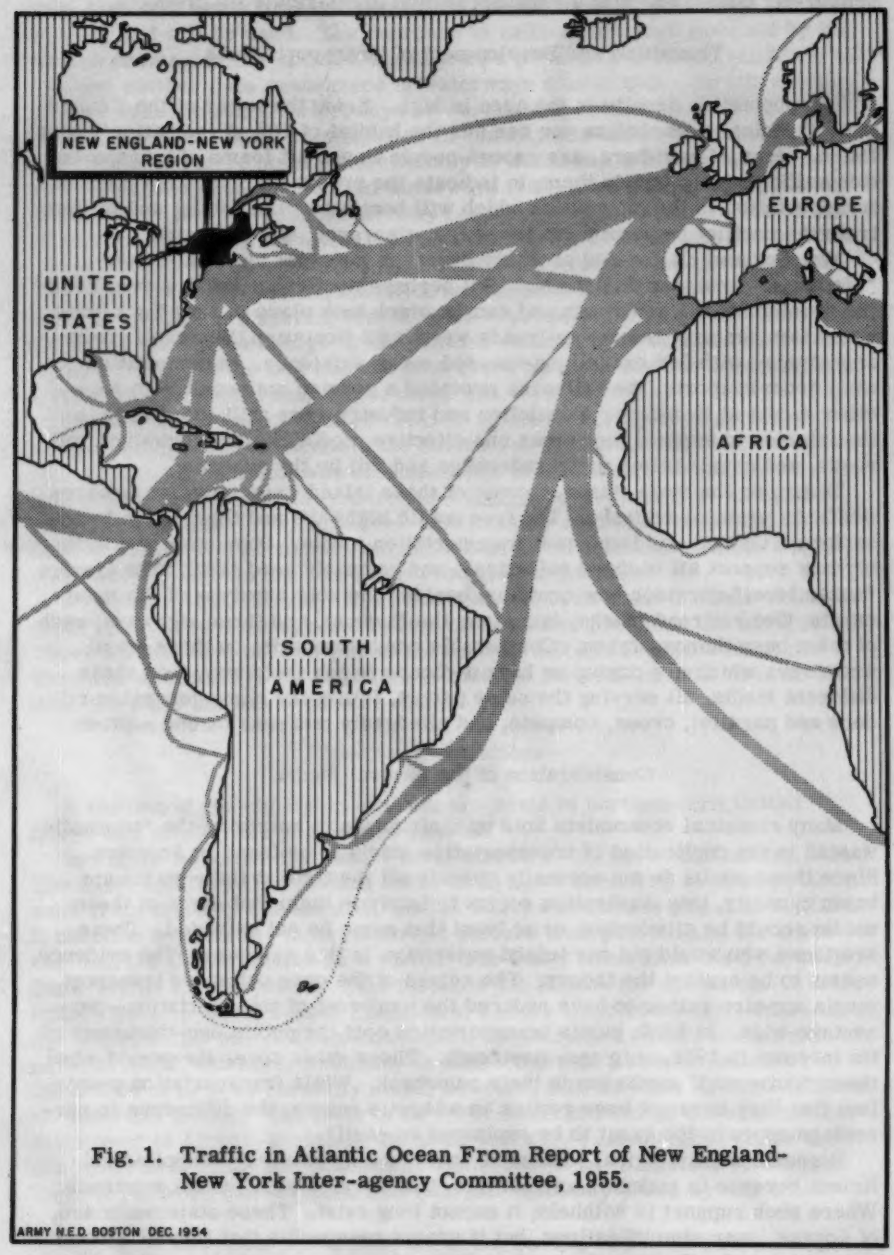

Fig. 1. Traffic in Atlantic Ocean From Report of New England-New York Inter-agency Committee, 1955.

with the natural resources for that shop, except waterpower, and hence very sensitively concerned with all transportation to distribute its products.

Transition and Development of Transport Media

The population density in the area is high. From the tower of the Empire State Building in Manhattan you can see the habitat of 10% of the nation's population. Here, if anywhere, are enough people to use all forms of transportation sufficiently to justify them; to indicate the proper place of each form of transportation in the integration which will best serve the public; and to illustrate the conflict between them for space, clearance, and operation.

New England claims and probably deserves the right to be called the "Mother of American Railroads." But perhaps nowhere has there ever been the development of toll roads and canals which took place in New York State in the last century. As the railroads were built westward, these toll roads and canals—with few exceptions—passed out of existence. In competition away from seaports, the railroads provided a service not possible to any other media at that time. Population and industry were still too sparse in the interior to support more than one effective media, so free highways, toll roads, and canals failed to get patronage and fell by the wayside.

Today, on the main stems of some of these inland waterways, waterborne traffic is again in evidence. The free public highways and the toll roads are back with us again as important transportation media. Population and industry now support all of these selectively and certainly need them. The famous "water level" corridor now contains, besides the sole survivor of the many canals, five railroad tracks, (six along the Hudson), and three highways, each of them busy thoroughfares. Comparable conditions exist on those other waterways which are paying or have a chance to pay their way, i.e., these different media, all serving the same people, follow the same general corridors and parallel, cross, compete, and alledgedly trespass on one another.

Consideration of the Several Media

Many classical economists hold up their hands in horror at the "economic waste" in the duplication of transportation media to be found in America. Since these media do not normally operate all the time at their maximum basic capacity, this duplication seems to imply to them that some of these media should be eliminated, or at least that some be not extended. There are those who would put our inland waterways in this category. The evidence seems to be against the theory. The return of the once outmoded transport media appears rather to have reduced the total cost of transportation—percentage wise. In 1929, public transportation cost the public one-thirteenth of its income; in 1952, only one-nineteenth. These dates cover the period when these "outmoded" media made their comeback. While transportation people feel that they have not been getting an adequate return, the difference in percentage appears too great to be explained so easily.

It seems wholly logical to assume that if public patronage supplies sufficient revenue to maintain any service, that service justifies its existence. Where such support is withheld, it cannot long exist. These statements are, of course, over simplifications, but it seems reasonable that they do state a proper basis for justification and analysis of our transportation. That these principles operate, is demonstrated by the constant decrease in our railway

mileage, obsolescense and revival of some waterways, and the return of highways—especially toll roads—to importance in transportation. Unquestionably, they also exercise some control on the extent to which each of the media is being and will be used. The decrease in railroad mileage does not by any stretch of imagination indicate obsolescence or lack of need for railroads as a whole; neither does resurgence of waterways traffic under certain circumstances indicate that all waterways are to become economically sound arteries of transportation. Bulk commodities in quantity are the backbone of such traffic and therefore point generally only to mainstem waterways serving large population centers. Inland waterways traffic has been growing, but so has all other traffic. Inland waterways account only for about 1/16th of our total transportation effort, and the ratio can hardly be considered to be changing rapidly. The changes which have been and are occurring in transportation reflect the increase in population and industry, and the integration of the various media into a system best adapted to present public needs. They also doubtless reflect the change in the relative value of each of these media due at least in part to the fact that the public now has, can use and does support, a wider selection of transport services than formerly.

These strictly transportation considerations are of great importance to all surface transportation media in the solution of the navigation clearance problem, because they should and doubtless will be the factors which, in the end, will determine whether any particular watercourse will support navigation and need provision for clearances. One existing media, or its actual or fancied possibility, should not impose a cost on other media without a corresponding benefit to the consumer who pays all the bills.

As noted by Mr. Kurylo,[2] basic studies have been made of some of the costs involved to highways and railways because of provision for navigation. These studies have become public documents, and are available as such. They are elementary, but sufficient to indicate the problem, the need of action, and point the way to further study.

Specific Illustrations

A resume of the highlights of these problems in northeastern United States will amplify the preceding remarks.

In Figure 2 you see the "water level corridor" we have been talking about. The name applies to the Hudson River from New York City to Albany, and west from there up the Mohawk, Oneida Lake, and Ontario plains to Buffalo. It contains some of the most important surface transportation in the northeast and the United States as a whole. The heavy lines show the New York State Barge Canal System. This includes the Hudson for operation. A main branch goes up through Lake Champlain, a more truly water level route than the Mohawk. By way of Lake Champlain, the Richelieu River, and a small parallel canal, tidewater at Albany is connected with tidewater below Montreal. It is to be carefully noted, however, that this fact in itself induces no waterway traffic. The State of New York built the Barge Canal in the corridor west of Albany, beginning about 50 years ago, after traffic on the then too small Erie Canal had practically vanished. What is now the New York Central Railroad had occupied this corridor for many years by that time.

2. "Bridge Clearances: The Interest of the Bureau of Public Roads," by Walter Kurylo.

Fig. 2. The "Water Level Corridor" and Present New York State Barge Canal System. (Courtesy New York Times) Vaughn Gray, Del.

Fig. 3. Mohawk River at Canajoharie. Corridor Packed with Transport Facilities. The New York Thruway under construction. Route 5 is to its right. Route 5-S is off to left of picture. Trusses at Lock carry movable dam mechanism.

There are 309 highway and railway bridges over the canal system. Since both highways and canal are under a common stewardship, it would be reasonable to assume that each would be treated as equitably as possible. The state chose to require 15 feet of clearance above canal water level, for a canal limited in depth to 12 feet over lock sills. In a modernization program begun during the depression, certain sections are proposed to be and are being given 20 feet of clearance.

Under such conditions, the shipper built his craft accordingly. Figure 4 shows a typical tow operating on the canal (and the Hudson). Note that the mast carrying the after range light is hinged. The funnel is just even with the pilot house. Figure 5 shows the basic limitation of the size of tow. It fills the lock. (Of historical interest, the locks giving entrance to the old Erie Canal are visible at the right. Today's transport requirements would ignore so small a watercourse.) For dry cargo, a somewhat different craft is used—an articulated, self-contained connection of barges. These barges are the full width of the locks—less 12". A power section complete with pilot house is used at the stern of the arrangement. Note that there are no stacks or fixed projections other than the pilot house. Each of these tows carries about a trainload of cargo. When empty, these Barge Canal craft have a freeboard of 12 to 14 feet, and the pilot house has to be lowered to pass under bridges. The lowered pilot house is shown in Figure 7.

These illustrations show what can be done if you have to do it, as against the concept that the structures over the waterway must clear a vessel designed with no compulsion for any limitation.

By contrast, Figure 8 shows a typical tow on the Mississippi River system, where a 9-foot channel prevails, and much of the cargo moves upstream against a stiff current. Here a trainload of cargo has little attraction to the operator. Coal, once a major tonnage on the lower Mississippi, now moves along that part of the river mostly by rail—and often by trainload. Mississippi tows have the cargo capacity of modern deep sea transports—four, five or six trainloads. Notice that the funnels usually form the highest projection on these Mississippi tows. The modern Mississippi towboat, even under a ruling clearance fixed by older vessels or maintenance equipment, and so having little or no compulsion toward restriction of vessel height, gets along with a pilot house at most 25 to 30 feet above the water level. They have generous funnels, but even these do not use up available clearance. They all have diesel engines. Many of them use the engines designed and built for the ubiquitous World War II LST. These ships had no stacks for engine exhaust. To the best of the writer's knowledge, no LST was ever lost at sea; while burnt to the water's edge sometimes in combat, none were lost in action. It does not appear that funnels would improve that record for safety or performance.

In former years, Albany was connected with New England and other parts of the world by fleets of the type of vessel shown in Figure 9. This was the freight and passenger carrier when navigation on the Hudson was in its heyday. This craft probably had a lot to be with fixing the clearance of the Brooklyn Bridge. They generally had a 95' keel and 125 to 130' masts. In its day, hundreds of the schooners illustrated could be seen at any time in the Harbor Basin at Albany. The last remnant of this basin is now being filled in, primarily to provide a bypass to keep truck traffic off the downtown streets of Albany. The modern Port of Albany is now well below the lowermost bridge which serves Albany and spans the Hudson.

In the 10 mile stretch of river above the present Port, there are three

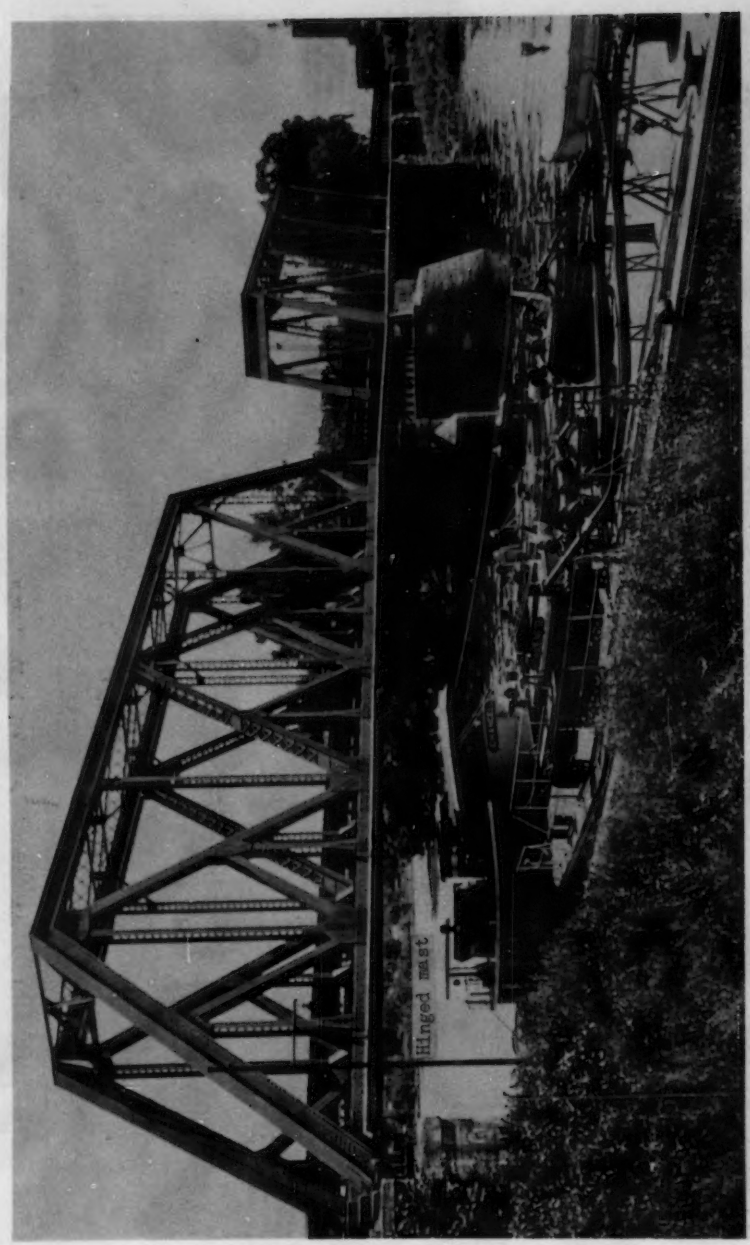

Fig. 4. Typical Barge Canal Oil Tow. Note hinged mast at stern.

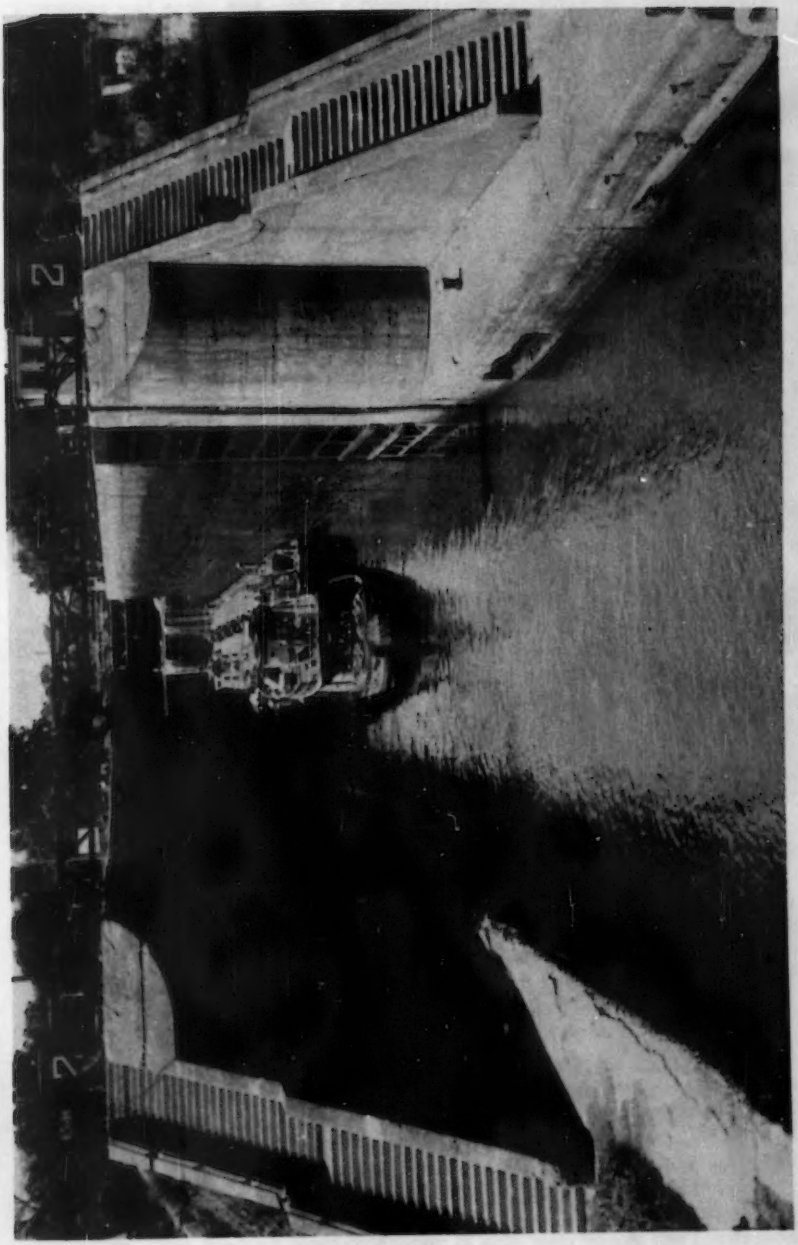

Fig. 5. Oil Tow in Waterford Lock.

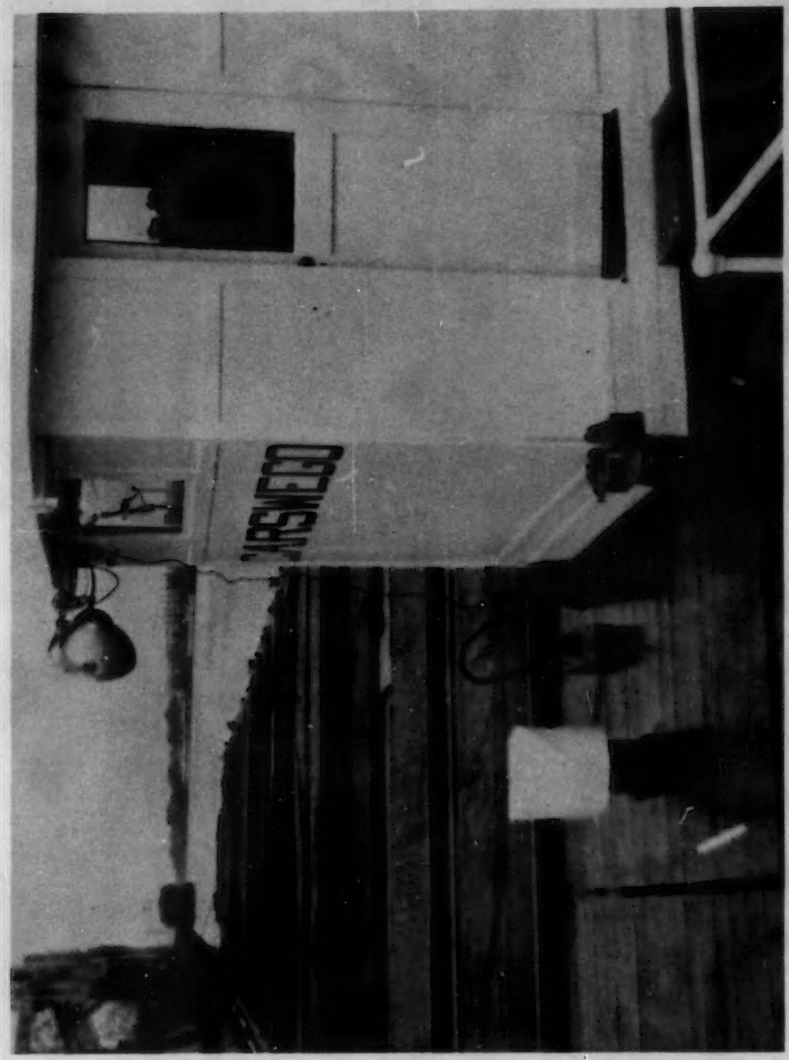

Fig. 6. Typical Dry Cargo Tow as used on Barge Canal

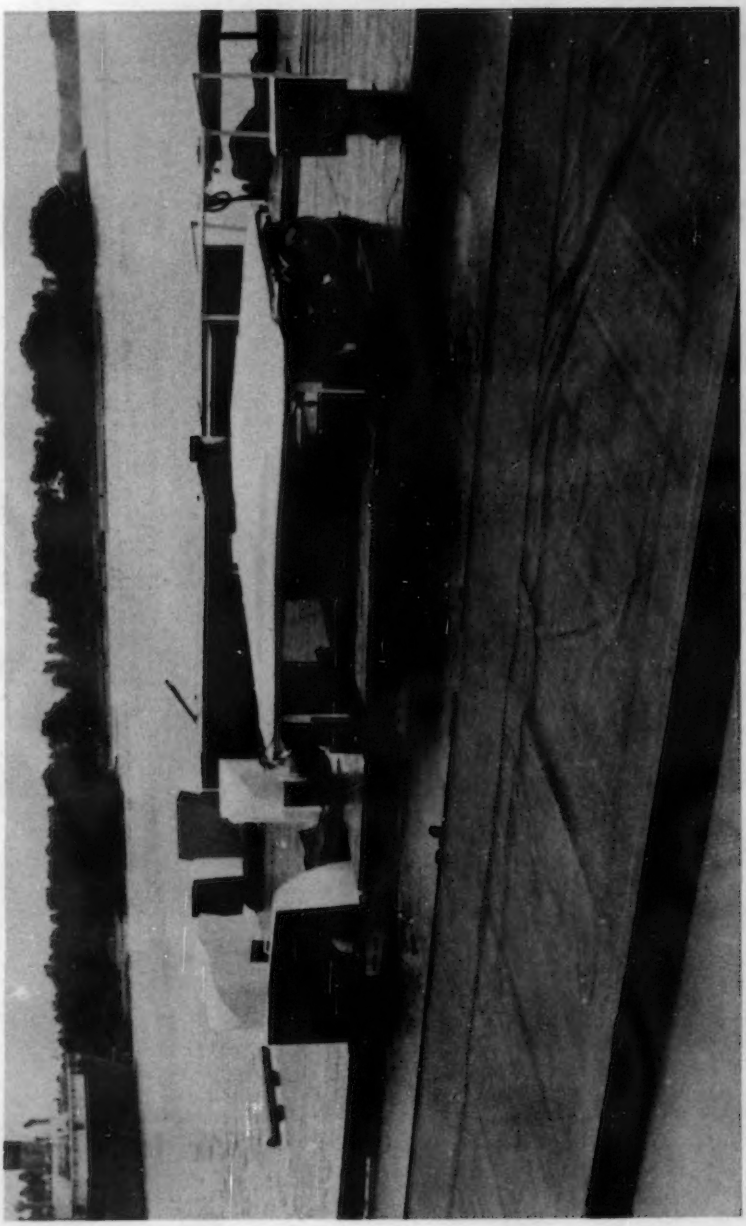

Fig. 7. Dry Cargo Tow—Pilot House Lowered

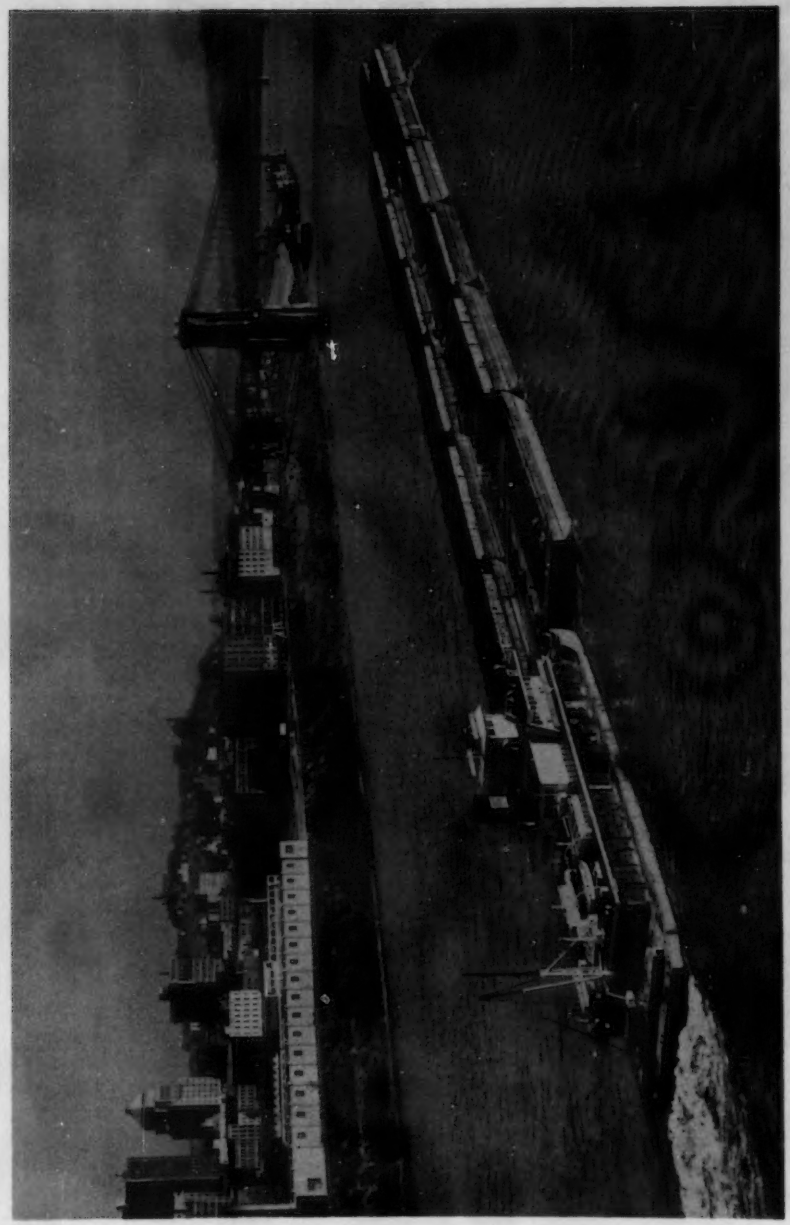

Fig. 8. Typical Mississippi System River Tow (Courtesy Corps of Engineers)

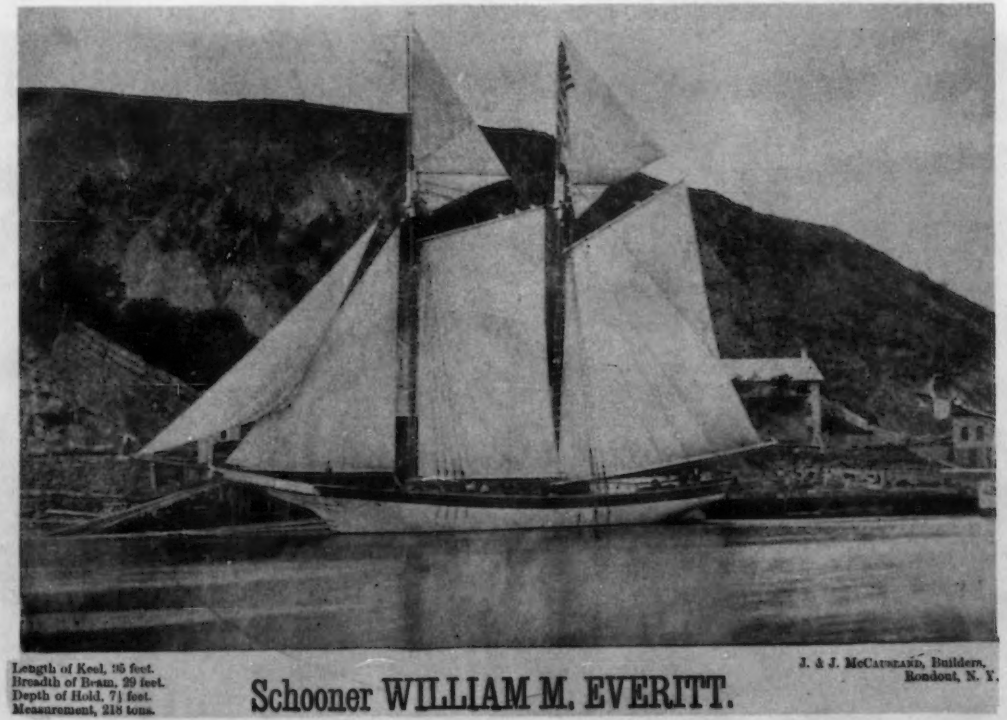
Length of Keel, 95 feet.
Breadth of Beam, 29 feet.
Depth of Hold, 7½ feet.
Measurement, 218 tons.
Schooner WILLIAM M. EVERITT.
J. & J. McCausland, Builders,
Rondout, N. Y.

Fig. 9. Former Workhorse on the Hudson and Coastal Waters.
Schooner William M. Everett (Courtesy Henry M. Stoneman, Jr.)

vertical lift bridges giving clearances of over 130 feet, and three swing bridges. Above that point only fixed bridges with Barge Canal clearances are to be found. There is no traffic above the Port of Albany, now or in prospect, other than substantially that for the Canal System. In the not too distant future another bridge over the Hudson will be needed to connect Albany to its suburbs. An important question will then be faced, which will find its counterpart in many places in the United States: shall this new bridge provide the same clearances as the old bridges above and below it, just because they so exist, or for the navigation then existing and in prospect?

At the other end of the Hudson is New York City—one of the world's major ports. A view of this port, looking toward the Narrows, is shown in Figure 10. Note that this port has been kept clear of obstructions. The lowermost bridge over the Hudson, the George Washington Bridge, is shown in Figure 11. Even this bridge is no obstruction. The clearance of over 250 feet is more than 50 feet greater than needed by any vessel now or in prospect. The proposed lower deck on this bridge will use only a fraction of this excess clearance. Manhattan Island dominates the city and the port. The island is surrounded by the Hudson, the East, and the Harlem Rivers. The East River connects the Hudson with Long Island Sound; the Harlem connects the Hudson and East Rivers. The Boroughs of Brooklyn, Queens, and Bronx lie east of Manhattan, and these four surround the work area of the New York part of the port. The first permanent bridge to be built in the port, the Brooklyn Bridge, is the lowermost bridge over the East River. This bridge fixed the clearance over the East River at about 132 feet. Even so, sailing vessels, which carried the world's cargo when that bridge was built, removed their topmasts to pass under it. The Brooklyn Navy Yard was then and is now above this bridge. All other bridges over the East River have about the same vertical clearance, the Triboro Bridge being the latest and uppermost. The "spieler" on one of the boat tours which circles Manahttan singles out this bridge to illustrate a point: ". . . . . this bridge will wind up to 137 feet above the water for any vessel that needs the clearance. The cars on the road have to wait. Before the cars can cross, they have to pay a toll. The ship goes for free. I don't get it!" He voices a not uncommon feeling.

In Figure 12 you see the Harlem River. The Harlem River may be called the housekeeping part of the port. Ashes and garbage loom large in its traffic. There are bridges every few blocks. There are also tunnels which you don't see, and which generally cost twice as much as a bridge. Topography fixed the clearance of a few of these bridges, but most of them are swing bridges.

A closer look at the Harlem will be profitable. Figure 13 shows one type of craft which requires the Harlem bridges to open. It happens that this craft is owned by a railroad, which uses this means of delivering its goods. Over an extended period of observation, only one other type of craft using this waterway did require bridge openings—a sailing yacht, with a mast 40 feet or more in height. Figure 14 shows the answer to that. This picture was taken on the Harlem River.

All craft regularly using the Harlem River are required by Corps of Engineers' regulation[3] to accommodate themselves to a clearance of 24 feet so that the bridges need not be opened. This is sufficient clearance even for the barge loads of freight cars which are freely shunted up and down the Harlem and around the harbor.

3. Bridge Regulation, Corps of Engineers 203.160

Fig. 10. Port of New York Looking Toward the Narrows (Fairchild Photo)

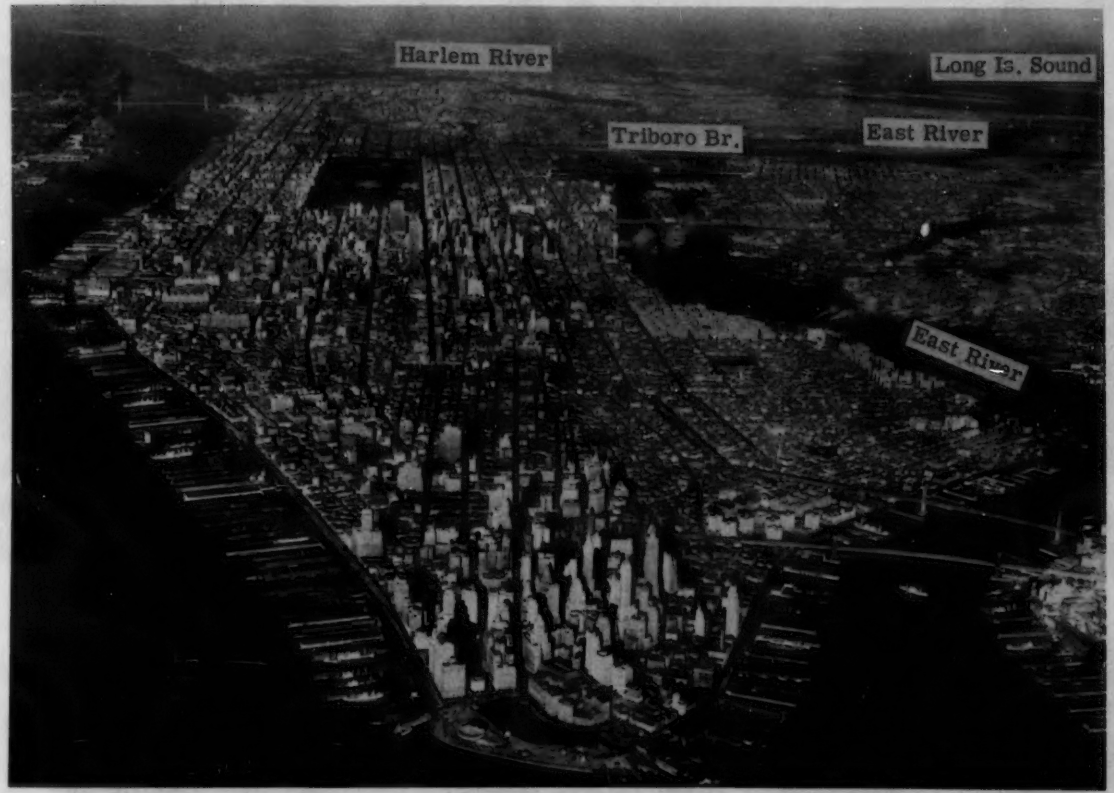

Fig. 11. Port of New York Looking up River from over Staten Island (Photo by Fairchild)

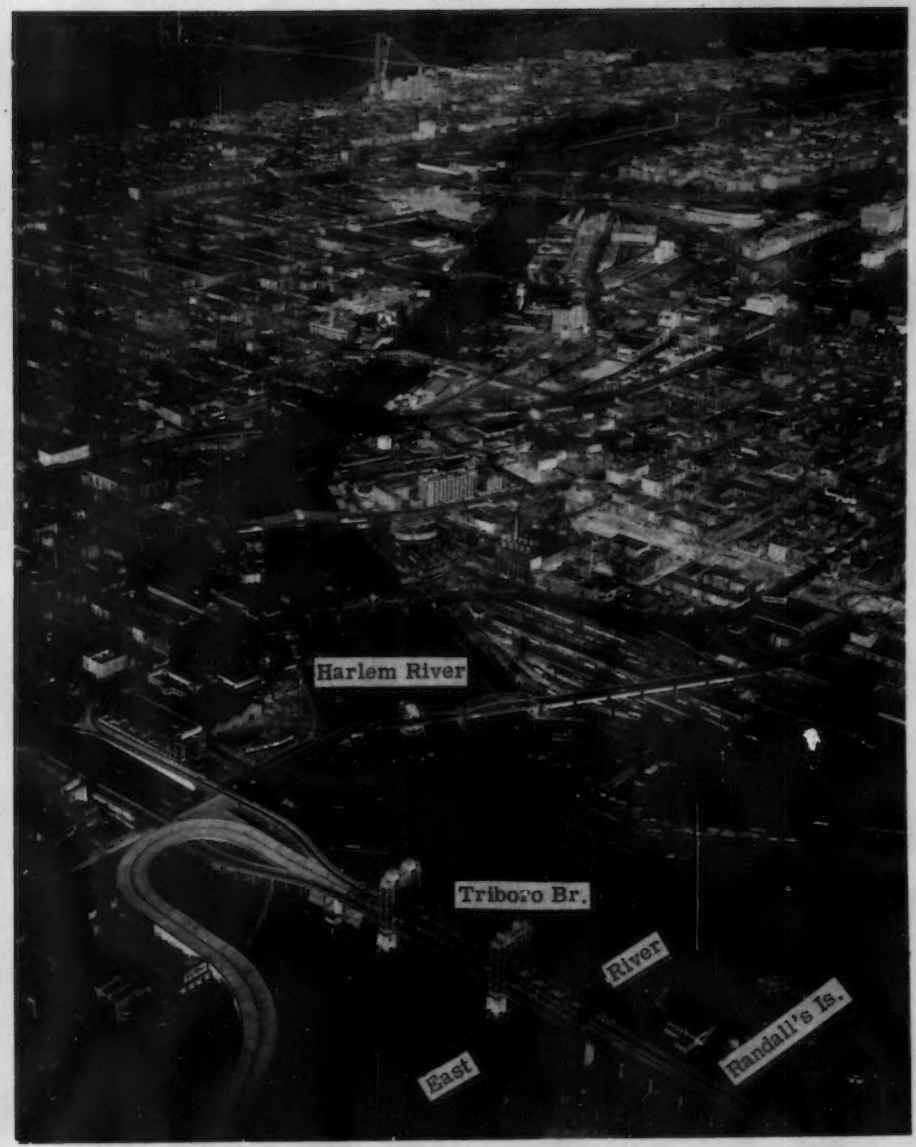

Fig. 12. Port of New York Looking up the Harlem River (Courtesy Triboro Bridge Authority. Photo by Fairchild)

Fig. 13. Work Craft on the Harlem River

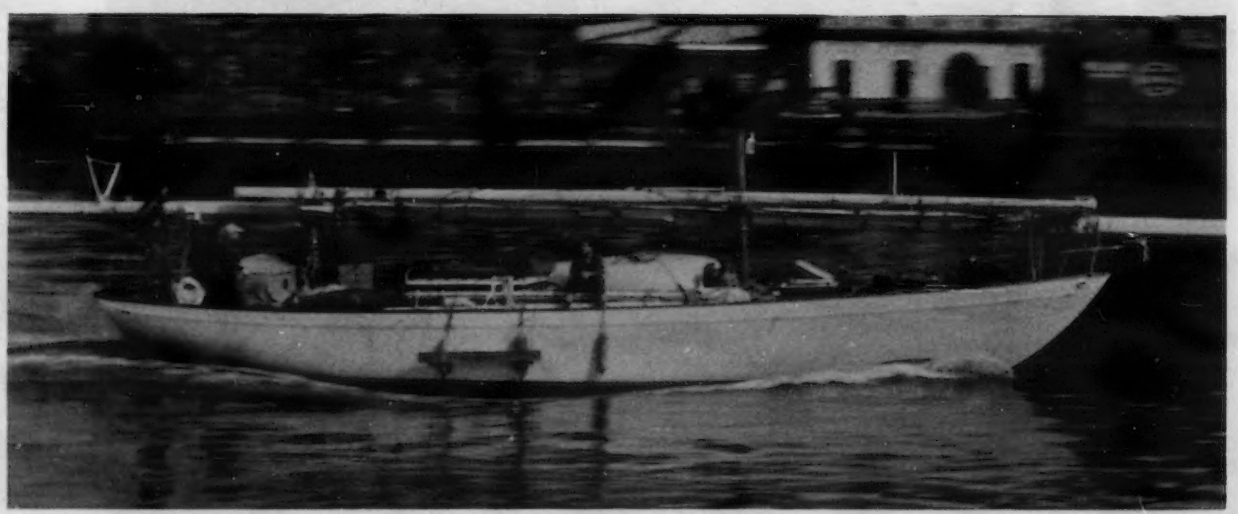

Fig. 14. Sailing Yacht. Masts unshipped for Transit down Harlem River.

The aerial view of Harlem River shown is not quite up to date. No recent similar picture is available. One of the bridges shown there carries the New York Central passenger trains into New York City. There are about 600 train movements a day over this bridge—which works out about one every 2 1/2 minutes. This bridge is being replaced by a lift span to clear 139 feet. The lift span alone adds at least $5,000,000 to the cost of the bridge, (out of a total cost of nearly $20,000,000), to say nothing of the cost of train delay and bridge operation. It can be left to the imagination of the reader what the opening of this bridge will do to train movements.

It is certainly within reason to expect that an objective analysis will find that all craft which use this waterway can properly be modified to conform to the 24 feet required of other vessels, and so eliminate movable bridges here entirely.

A few other examples are appropriate.

The Charter Oak Bridge crosses the Connecticut River at Hartford. A powerhouse serving the area lies downstream of the bridge. Fuel need not pass under the latter.

The Buckley Bridge is a short distance upstream, from the Charter Oak bridge. There is no record of any traffic of consequence passing under the Buckley bridge or above it. The extra cost of providing 80 feet of clearance for the 300,000 tons of waterborne traffic passing under the Charter Oak bridge was 4 1/2 million dollars. Its annual cost is over $100,000 a year—a public cost of 33¢ for every ton. The traffic consists of petroleum products, which could be pumped to any tank farm just as well from below the bridge as from above. Navigation here is of long standing; the pattern should now be reasonably fixed. Why not have zoned the area above the Charter Oak Bridge to save this expenditure?

The Zoning Problem

This brings up a point of some consequence. Great objection is made, when cases of this kind are pointed out that such zoning restrictions would deny the use of navigable waters to anyone who might wish to locate a business that could, would, or might use navigation. Such objection implies that navigation is an entity which has "riparian" rights on the lands bordering the waters and that no community should have the right to zone its area to prevent the establishment of a business which could impose unreasonable costs on that community. Yet, since a navigable waterway is, under the law, protected against any encroachment, such zoning could well be ineffective without an Act of Congress. There are many instances of a single establishment so located as to require added expenditure for a crossing far in excess of the value of the business to the community or to the owners. Even where the laws of the state would require full compensation to any owner (and they usually do) for the physical loss of navigation at his doorstep, the right of the community to build over navigable waters without providing for navigation can be and is still denied.

The Congress has never defined navigation nor set up criteria for determination of the conditions under which a waterway should be considered navigable. In the absence of such definition, however, Supreme Court decisions many years ago had in effect defined a navigable stream as one which "was navigable in fact, in a commercial sense, and in its ordinary condition." In those days, it was generally possible to obtain a statement giving the location

Fig. 15. Charter Oak Bridge, Hartford, Connecticut

of the head of navigation on all streams, above which no permit or Act of Congress was needed for a crossing. With the passage of many laws in the development of water resources in the last generation, however, the Supreme Court decision of 1899[4] appears to be general guidance. This decision, referring to a proposed diversion of water for irrigation, stated:

> "It is not a prohibition of any obstruction to the navigation, but any obstruction to the navigable capacity, and anything, wherever done or however done, within the limits of the jurisdiction of the United States which tends to destroy the navigable capacity of one of the navigable waters of the United States, is within the terms of the prohibition"
>
> (Italics are author's)

As an employee of a midwestern highway department, the writer well remembers being notified that plans for a bridge well above a head of navigation, previously given in writing, were approved only on condition that an Act of Congress be obtained to authorize it. This bridge was to be in backwoods country over a stream about wide enough for the village stove warmers to spit across. One Federal agency had found that a dam might be built in the neighboring state, and might make the stream navigable. The dam had not been built or authorized! There was no assurance that it would be. The situation was not helped by the fact that the writer's State had given a firm promise to build the bridge before the seasonal rains, and the adjournment of Congress was only a week away.

It is, then, quite understandable that a firm determination of the "head of navigation" can no longer be obtained except by Act of Congress. The State of Connecticut has recently gone to that cumbersome method in three instances, as indicated by Mr. Kurylo. The State of Massachusetts has done likewise in the case of the Fort Point Channel, in the heart of Boston, alongside its South Station, after previous experience on the Neponsett River in trying to buy out an upstream property owner so that excessive provision for navigation would not be necessary. This channel had become of no commercial value to the Port, and was crossed by eight movable bridges in the heart of the city near its South Station.

Reverse Riparian Rights

This thing which, for lack of a better name, we may call "reverse riparian rights" is a more serious problem than any record will show. We are accustomed to think of land having riparian rights over water, not water over the adjoining land. The courts say that navigation is not a property right; no landowner can acquire it by virtue of his title; apparently no community can extinguish it by zoning or purchase. As of now, no agency can declare any stream non-navigable. Only Congress can do so.

In many minds navigation has become a "justification" for almost any expenditure which anyone wishes to make in order to use water or protect himself against it. This thinking has magnified the effect of long standing law to the point where many people unconciously consider navigation so sacred as to transcend mere man made statute. This concept in the public mind has been fostered by and for many honest and well meaning interests not even remotely connected with navigation. It is perhaps the most serious hinderance to objective thinking which we face in developing our water resources.

4. United States vs Rio Grande Irrigation Co., 174 U.S. 690,708 (1899). See Act of September 10, 1890, §10, 26 Stat. 426, 454.

Whether the actuality of the many extravagant claims purporting to benefit navigation are imaginary or substantial is immaterial in law. If the Congress says a specific Act is in the interest of navigation, the courts will not entertain any question as to "fact." The Congress in 1944 recognized the interest of the states in their own resources and did declare it as a policy that the State's right to develop its own water resources was to be respected, and navigation would be considered by the Congress only if substantial. That it protected its own time and effort by this declaration may not have been incidental. This declaration, however, while serving notice and encouraging policy development, sheds little light. What is "substantial"—and to whom?

Criteria and Application

There are no overall criteria for navigation clearances. These must be worked out in each case by the conflicting interests, and since the existing law so requires, in favor of navigation. At best, results are arrived at on a trading basis. If the record be accepted, many "satisfactory" solutions have been reached. More likely most of these were compromises and satisfactory to no one. This is invariably the case where no rule or principle, justified by experience and known beforehand to all concerned, is available.

Mr. Kurylo[2] has limited his remarks to those situations which are physically common to waterways having navigable depths of no more than 12 feet. This embraces the major portion of the geographic area of the United States. Such channels carry less than 10% of our total waterborne tonnage however. Incidentally, 40% of the total waterborne commerce in our rivers and ports consists of petroleum products—a prime requisite for highway construction and motor vehicle fuel. It is, therefore, not in the least far fetched to assume that the rise of highways in importance as a transport media has been a major element in the return of inland waterways traffic to importance. This is merely another aspect of transport integration.

The foregoing citation of conditions, particularly of but not confined to northeastern United States, in the writer's opinion, makes it clear that the navigation clearance problem is not limited to channels under 12' in depth but is a matter affecting transportation everywhere. Everyone is concerned in the problem. Everyone concerned will be better served if clear and equitable criteria are established and applied, so that everyone knows beforehand what streams are navigable and to what extent. This need not and should not be a rigid and inflexible determination. The appearance of this subject on the convention agenda demonstrates the effect of rigidity and inflexibility in the past.

SUMMARY

It may appear that the writer has given more attention to transportation per se than to the announced subject. But the navigation clearance problem is a transportation problem, and it is believed that a clearer concept of any facet of a problem is possible if the problem as a whole is clarified. Objectively viewed, navigation is only one medium of transportation and not by any means the major one. There is nothing sacred about it. In our development as a nation, we have used successively waterways, highways, toll roads, railroads, and air transport. Some of these once nearly disappeared, but are now

back with us. There is nothing mysteriously cyclic about that. It is not a question of whether we should have one or the other or that they share the traffic equally or that one may be more important than another. Our economy can use all of them. Each have advantages and disadvantages. The public is integrating them into their most useful pattern by its patronage. As noted previously, navigation clearances are important because of the role they play in that integration for best service to the public. This integration has a selective pattern, not a uniform one. Proper integration can take place only when the total cost to the public is at its minimum. Costs for navigation clearances are usually a major item to the public. And, until and unless criteria for them are established and applied to every watercourse in the nation, the present legalistic concept of "navigation" literally applied, is a lien or encumbrance on every riparian ownership of every rill and trickle in the land. We cannot assume that "it can't happen here." It already has.

Certainly history has shown us that each generation must view its affairs in the light of its own environment and occupy itself with corrections of old and the solutions of new problems. This constant need of society we are facing here. We, in the Bureau of Public Roads, feel that something has to be done about navigation clearances. We are engaged in the doing of it. We intend to continue until a wholly satisfactory and equitable solution is reached.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW) Divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate Issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of the publication Journal in which the paper appeared. For example, Paper 881 is identified as 881 (SM1) which indicates that the paper is contained in Issue 1 of the Journal of the Soil Mechanics and Foundations Division.

VOLUME 81 (1955)

APRIL: 659(ST), 660(ST), 661(ST)[c], 662(ST), 663(ST), 664(ST)[c], 665(HY)[c], 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)[c], 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 688(SA)[c], 689(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)[c], 700(PO), 701(ST)[c].

JUNE: 702(HW), 703(HW), 704(HW)[c], 705(IR), 706(IR), 707(IR), 708(IR), 709(HY)[c], 710(CP), 711(CP), 712(CP), 713(CP)[c], 714(HY), 715(HY), 716(HY), 717(HY), 718(SM)[c], 719(HY)[c], 720(AT), 721(AT), 723(SU), 723(WW), 724(WW), 725(WW), 726(WW)[c], 727(WW), 728(IR), 729(IR), 730(SU)[c], 731(SU)[c].

JULY: 732(ST), 733(ST), 734(ST), 735(ST), 736(ST), 737(PO), 738(PO), 739(PO), 740(PO), 741(PO), 742(PO), 743(HY), 744(HY), 745(HY), 746(HY), 747(HY), 748(HY)[c], 749(SA), 750(SA), 751(SA), 752(SA)[c], 753(SM), 754(SM), 755(SM), 756(SM), 757(SM), 758(CO)[c], 759(CO)[c], 760(WW)[c].

AUGUST: 761(SD), 762(ST), 763(ST), 764(ST), 765(ST)[c], 766(CP), 767(CP), 768(CP), 769(CP), 770(CP), 771(EM), 772(SA), 773(EM), 774(EM), 775(EM), 776(EM)[c], 777(AT), 778(AT), 779(SA), 780(SA), 781(SA), 782(SA)[c], 783(HW), 784(HY), 785(CP), 786(ST).

SEPTEMBER: 787(PO), 788(SD), 789(HY), 790(HY), 791(HY), 792(HY), 793(HY), 794(HY)[c], 795(EM), 796(EM), 797(EM), 798(EM), 799(EM)[c], 800(WW), 801(WW), 802(WW), 803(WW), 804(WW), 805(WW), 806(HY), 807(PO)[c], 808(HY)[c].

OCTOBER: 809(ST), 810(HW)[c], 811(ST), 812(ST)[c], 813(ST)[c], 814(EM), 815(EM), 816(EM), 817(EM), 818(EM), 819(EM)[c], 820(SA), 821(SA), 822(SA)[c], 823(HW), 824(HW).

NOVEMBER: 825(ST), 826(HY), 827(ST), 828(ST), 829(ST), 830(ST), 831(ST)[c], 832(CP), 833(CP), 834(CP), 835(CP)[c], 836(HY), 837(HY), 838(HY), 839(HY), 840(HY), 841(HY)[c].

DECEMBER: 842(SM), 843(SM)[c], 844(SM), 845(SU)[c], 846(SA), 847(SA), 848(SA)[c], 849(ST)[c], 850(ST), 851(ST), 852(ST), 853(ST), 854(CO), 855(CO), 856(CO)[c], 857(SU), 858(BD), 859(BD), 860(BD).

VOLUME 82 (1956)

JANUARY: 861(SM1), 862(SM1), 863(EM1), 864(SM1), 865(SM1), 866(SM1), 867(SM1), 868(EM1), 869(ST1), 870(EM1), 871(HW1), 872(HW1), 873(HW1), 874(HW1), 875(HW1), 876(EM1)[c], 877(HW1)[c], 878(ST1)[c].

FEBRUARY: 879(CP1), 880(HY1), 881(HY1)[c], 882(HY1), 883(HY1), 884(IR1), 885(SA1), 886(CP1), 887(SA1), 888(SA1), 889(SA1), 890(SA1), 891(SA1), 892(SA1), 893(CP1), 894(CP1), 895(PO1), 896(PO1), 897(PO1), 898(PO1), 899(PO1), 900(PO1), 901(PO1), 902(AT1)[c], 903(IR1)[c], 904(PO1)[c], 905(SA1)[c].

MARCH: 906(WW1), 907(WW1), 908(WW1), 909(WW1), 910(WW1), 911(WW1), 912(WW1), 913(WW1)[c], 914(ST2), 915(ST2), 916(ST2), 917(ST2), 918(ST2), 919(ST2), 920(ST2), 921(SU1), 922(SU1), 923(SU1), 924(ST2)[c].

APRIL: 925(WW2), 926(WW2), 927(WW2), 928(SA2), 929(SA2), 930(SA2), 931(SA2), 932(SA2)[c], 933(SM2), 934(SM2), 935(WW2), 936(WW2), 937(WW2), 938(WW2), 939(WW2), 940(SM2), 941(SM2), 942(SM2)[c], 943(EM2), 944(EM2), 945(EM2), 946(EM2)[c], 947(PO2), 948(PO2), 949(PO2), 950(PO2), 951(PO2), 952(PO2)[c], 953(HY2), 954(HY2), 955(HY2)[c], 956(HY2), 957(HY2), 958(SA2), 959(PO2), 960(PO2).

c. Discussion of several papers, grouped by Divisions.

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